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EFFECT OF SOME ENZYMES TREATMENT ON RHEOLOGICAL BEHAVIOR OF STRAWBERRY JUICE AND ITS CONCENTRATES

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ABSTRACT

Strawberry juice (7.5 °Brix) was prepared and treated with (Pectinex™ and Rohament MAX) enzymes at different dosages (0, 300 and 600 ppm) after that the strawberry juice preparations were concentrated to 2, 3 and 4 folds. Rheological properties of these preparations were studied at a temperature range 5-80 °C and shear rate range 0.3 to 100 s^{-1} by using Brookfield Digital Viscometer Model DV-II+. The Bingham, Casson, IPC Paste and Power Law rheological models were applied to describe the rheological properties of all preparations. These properties are key parameters required to solve food industry problems in numerous areas: quality control, evaluation of consumer acceptance or texture (including physicochemical changes which occur during processing and storage). The results indicated that strawberry juice preparations behave as non-Newtonian fluids (pseudoplastic) and have a definite yield stress. The Bingham & Casson plastic viscosity & yield stress, 10 RPM viscosity, consistency index and flow index, decreased with increasing enzyme dosage. Rohament MAX enzyme was more effective in reducing viscosity and rheological parameters than Pectinex™ enzyme at different concentrations and temperatures. The effect of temperature on the viscosity can be described by means of an Arrhenius-type equation. The activation energy for viscous flow depends on the total soluble solids. The (Bingham & Casson plastic viscosity and yield stress, 10 RPM viscosity, consistency index and flow index) decrease with increase of temperature. Sensory evaluation for all preparations were carried out.

Keywords: Strawberry juice. Enzymes treatment. Chemical composition. Rheological parameters. Flow behavior. Activation energy. Sensory characteristics.

INTRODUCTION

Studies on rheological behavior of strawberry juice and its concentrates, like other fluid foods, could be important for applications related to handling, storage, processing, quality control, and sensory analysis of foods. Most liquid food materials, including fruits juice fall into the pseudoplastic classification, which yields curves with slopes that decrease as shear rate increases, i.e., the flow behavior index "n" varies between 0 and 1. This means that {apparent viscosity decreases as the shear rate increases (shear thinning fluids)}. Like the Newtonian viscosity, the constant K increases exponentially with increase of soluble solids of juice and it decreases sharply at higher temperatures. The shear rate "γ" in a given flow system can be estimated from the linear or rotational velocity of the fluid and geometry of system. High shear rates, resulting in relatively low apparent viscosities, are desirable in pumping and various heat and mass transfer operations of pseudoplastic food products. Temperature has a relatively small effect on the flow behavior index (n), meaning that the apparent viscosity of non-Newtonian (Pseudoplastic) fluids depends mainly on the shear rate (Saravacos and Kostaropoulos, 1995).

The application of commercial enzyme preparation is one of the advanced technology today. Stutz (1989) reported the following advantages which can be obtained by applying these enzymes in juice processing:

a) Viscosity reduction is very important from economical, technological and quality points of view.
b) Modification of the fruit macro-molecules (of the-cell-wall) improves cloud stability (cloudy juices) or enhances clarification process (clear juices).
c) Making possible the utilization of existing equipment which is much cheaper, for juice extraction from various fruits in the same factory instead of very expensive specific equipments.

The aims of using enzymes in fruit and vegetable processing; classical, pectolytic enzyme and amylase were used in fruit and vegetable processing;. modern enzyme preparations including those with cellulase, hemicellulase etc., activity manufacture of haze-stable low-viscosity juices, whole-fruit pulps, turbid concentrates and dried products. preparation of totally-liquidized fruit and vegetable hydrolysates from raw materials with solid, hard structure and liquefaction of fruit with a soft structure (Schmitt, 1984).

Quality characteristics of juices prepared by treating fruit pulps with pectinolytic enzyme were evaluated by (Joshi *et al.*, 1991). Addition of pectinolytic enzyme (pectinol) to the pulps of plum, peach and apricot increased juice yield, causing a slight change in total soluble solids, pH value and acidity, and a drastic decrease in apparent viscosity.

Enzymes enhance the concentratability of the juices and permit higher concentrations with no loss of quality or lower evaporation temperature with an increase in quality (Urlaub, 1992).

The objectives of this study were to study the effect of enzymes treatment on rheological behavior of strawberry juice and its concentrates with different soluble solids and the effect of temperature on the viscosity of strawberry juice and its concentrates either in the un-treated or enzymatic treated samples. Beside, study the effect of enzymes treatment on sensory characteristics.

MATERIALS AND METHODS

1. Materials:

1.1 Strawberry fruits were picked at the ripe stage from a certain farm in Kalyobia Governorate.

1.2 **Rohament MAX** enzyme is a highly concentrated enzyme preparation for the processing and liquefaction of fruits and vegetables. It contains an enzyme complex, whose single enzyme activities are specially macerating pectinases, cellulases and hemicellulases. It was obtained from Rohm GmbH, Chemical Fabrik, Germany.

1.3 **Pectinex™** enzyme is a highly purified preparation produced from a selected strain of *Aspergillus niger*. The product mainly contains pectin-transeliminase, polygalacturonase, pectinesterase and hemicellulases and is capable of breaking down pectic substances in fruits and vegetables. There are special products available for the processing of berries. It was obtained from Novo Nordisk Ferment Ltd, Switzerland.

2- Processing

Strawberry fruits were washed, dried in air and cut into small parts. The strawberry juice was extracted by Moulinex blender (Blender Mixer, type: 741). It took five minutes blending to get strawberry juice. The juice was strained by a stainless steel strainer, then strained again by a clean muslin cloth to get rid of seeds and peels for obtaining strawberry juice. The juice was divided into two parts.

1. The first part was divided into two portions. The 1st one to be used in measurements of chemical composition, rheological measurements and sensory evaluation.
   The 2nd portion to be used in preparation of different concentrations (2, 3 and 4 folds).
2. The second part was divided into four portions. The 1st and 2nd portions were treated by Rohament MAX enzyme at dosage 300 and 600 ppm. The 3rd and 4th portions were treated by Pectinex™ enzyme at the same enzyme dosages.

These four preparations were used to obtain different concentrations (2, 3 and 4 folds).

The enzymes reaction was allowed at 40-45°C for 2 hrs and then was inactivated by heating to 85°C with a residence time of 9-10 minutes.

A rotary evaporator at 45-50°C under vacuum (vacuum pump was used at 23-25 mm Hg absolute pressure) was used to obtain strawberry concentrates (2, 3 and 4 folds total soluble solids were 15, 22.5, and 30 °Brix, respectively).

3. Methods:

3.1. Analytical methods:

Moisture content, total solids, total soluble solids, ash, ascorbic acid and crude fiber were determined according to AOAC (1995). The pH was measured with a pH meter model Consort pH meter P107. Titratable acidity was determined by titration with NaOH 0.1 N solution using phenolphthalein as indicator according to AOAC (1995). Total and reducing sugars were determined by Shaffer and Hartman method as described in the AOAC (1995). Total pectic substances contents were determined by the method of Carre and Hayness, described by Pearson (1976). Pulp content was determined according to El-Mansy *et al.*, (2000 a,b). Color index of strawberry juice was determined by the method of Meydov *et al.*, (1977). Total anthocyanins were measured according to the method of Skalski and Sistrunk (1973). Specific heat (c_p) was calculated according to Alvarado (1991). Density was determined with a pyknometer at 25 °C according to AOAC (1995).

3.2. Rheological measurements:

Viscosity measurement was carried out by the Brookfield Digital Viscometer Model DV-II+ with 18 rotational speeds for comprehensive data gathering (0.3, 0.5, 0.6, 1.0, 1.5, 2.0, 2.5, 3, 4, 5, 6, 10, 12, 20, 30, 50, 60 and 100 rpm). The Brookfield spindles used were:

a- UL adapter b- Brookfield small sample adapter

Data was analysed by using Brookfield Software Rheocalc V1.

Bingham plastic, Casson, IPC Paste and Power Law math models provide a numerically and graphically analyse the behavior of data sets.

Bingham Plastic:

The Bingham equation is $\tau = \tau_o + \eta\gamma$ (1)

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) γ = Shear rate (sec^{-1})

The calculated parameters for this model are: Plastic Viscosity, Yield Stress and Confidence of fit according to Bingham (1922) and Malcolm (1982).

IPC Paste Analysis:

This method is intended to calculate the shear sensitivity factor and the 10 rpm viscosity value of pastes.

The Paste equation is $\eta = kR^n$ (2)

where:

η=10 rpm viscosity (cP) (mPa.s) k =Consistency multiplier (mPa.s)

R =Rotational speed (rpm) n = Shear sensitivity factor

The calculated parameters for this model are: Shear sensitivity factor (Dimensionless), 10 rpm Viscosity and Confidence of fit (%).

Power law:

The power law equation is $\tau = k\,\gamma^n$ (3)

where:

τ = Shear stress (N/m^2) γ = Shear rate (sec^{-1})

k =Consistency index ($mPa.s^n$) n = Flow index (dimensionless)

The calculated parameters for this model are: Flow Index (n), Consistency Index (k) and Confidence of fit (%).

Casson model:

$$\tau^{0.5} = \tau_o^{\ 0.5} + (k_c \cdot \gamma)^{0.5} \quad (4)$$

where:
τ_o = yield stress and $(k_c)^{0.5} = \eta_c$= Casson apparent viscosity (mPa.s).

Thixotropic behavior:

Calculation of thixotropy area was based on measuring shear rate from (0.3 to 100 sec^{-1}) and remeasuring back the same parameters using the reverse direction; from 100 to 0.3 sec^{-1}. The gab areas between the ascending and descending curves were measured using digital planimeter PLACOM "KP-90N" according to (Ramos and Ibarz 1998 and Sharoba 1999).

Activation energy and the effect of temperature on viscosity:

Activation energy was calculated using Arrhenius-type equation as mentioned by Ibarz *et al.* (1996), El-Mansy *et al.*, (2000 a, b) and Sharoba (2004):

$$\eta = \eta_\infty \exp (Ea/RT) \quad (5)$$

where:
η is the viscosity, η_∞ is a constant (is the viscosity at infinite temperature), Ea is the activation energy of flows (J/mol), R is the gas constant and T is the absolute temperature in °K.

3.3. Sensory evaluation:

Sensory tests were carried out by a properly well trained panel of 12 testers. They were selected if their individual scores in 10 different tests showed a reproducibility of 90%. Soluble solids of different preparations were adjusted using distilled water to be 7.5°Brix as the natural juice and evaluated of acceptability for texture (mouth feel), color, taste, odor and overall acceptability by each panellist separately, according to Sharoba (2004).

3.4. Statistical analysis:

Data for the sensory evaluation of all strawberry preparations were subjected to the analysis of variance followed by (L.S.D) analysis according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The results of the physico-chemical characterization of strawberry juice are shown in Table (1). The values obtained for juice are similar to those reported elsewhere (McCance and Widdowson's,1992 and Bahlol, 2000)

Effect of total soluble solids on rheological parameters of strawberry juice:

In recent years, viscosity had been taken as an important factor to differentiate between strawberry juice and strawberry juice concentrates, since many workers considered viscosity as a function of quality. This view led to conclude that one of the fundamental tools in determing strawberry juice quality is viscosity.

Table (1): Physico-chemical composition of strawberry juice

Components	Units	Strawberry Juice
Moisture	%	91.351± 0.146
Total solids	%	8.649 ± 0.092
Total soluble solids	°Brix	7.502 ± 0.014
Ash	%	0.492 ± 0.011
Titratable acidity	% (as citric acid)	0.944 ± 0.016
pH value	-	3.487 ± 0.026
Ascorbic acid	(mg/100 ml)	48.573 ± 0.707
Total sugars	%	4.470 ± 0.044
Reducing sugars	%	3.147 ± 0.031
Non-reducing sugars	%	1.323 ± 0.039
Total pectic substances	%	3.262 ± 0.063
Water soluble pectin	%	1.145 ± 0.024
Ammonium oxalate soluble pectin	%	0.977 ± 0.048
Acid soluble pectin	%	1.039 ± 0.011
Crude fiber	%	0.718 ± 0.038
Pulp Content (V/V)	%	45.27 ± 0.483
Color index	(O.D. at 420 nm)	1.546 ± 0.096
Anthocyanine	(O.D. at 535 nm)	18.69 ± 0.759
Specific heat capacity	kJ/kg K	0.9503 ± 0.001
Density at temperature 25 °C	(kg/m^3)	1043.33± 0.519

**Each value is the average of three replicates ± S.E.*
**Chemical composition on wet weight basis*

The rheological behavior of strawberry juices were studied in the concentration 7.5, 15, 22.5, and 30 °Brix and temperatures within the range 5-80°C. The experimental results of shear stress (τ) and shear rate (γ) indicate the non-Newtonian behavior (pseudoplastic behavior) at all assayed temperatures of those juices. The experimental results of rheological measurements were fitted to eqns. (1, 2 ,3 and 4). The results are given in Table (2). The plastic viscosity (η) (mPa.s), yield stress (τ_o) (N/m^2), 10 RPM viscosity (mPa.s), shear sensitivity factor (N), consistency index (k) ($mPa.s^n$) and flow index (n), generally, increased with increasing total soluble solids. The Bingham plastic viscosity (η) (mPa.s) was 61.23, 929.05, 1497.60 and 2014.8 (mPa.s) for 7.5, 15, 22.5, and 30 °Brix, respectively, at 20°C. Also the Bingham and Casson plastic viscosity (η) (mPa.s) decreased with increasing temperature.

The yield stress for Bingham and Casson models (τ_o) (N/m^2) increased with increasing total soluble solids. The Casson (τ_o) values were 2.65, 4.36, 5.85 and 15.82 N/m^2 for the formentioned juices, respectively, at 80°C. The yield stress decreased with increasing temperature. The 10 RPM viscosity increased with increasing total soluble solids. They were 412.10, 6955.80, 12125.50 and 19706.30 for the forementioned juices at 60°C, respectively. The consistency index (k) ($mPa.s^n$) increased with increasing total soluble solids. The consistency index (k) values were 2914, 12901, 24526 and 40125 ($mPa.s^n$) for the forementioned juices at 40°C, respectively.

Table (2): Rheological parameters of strawberry juice and its concentrates.

Strawberry juice concentration	Temp. (°C)	Parameters for different models												Thixotropy ($Pa.s^{-1}$)
		Bingham			Casson			IPC paste			Power law			
		$\eta_{(B)}$	$\tau_{o(B)}$	Conf. %	$\eta_{(C)}$	$\tau_{o(C)}$	Conf. %	10 RPM visc.	N1	Conf. %	K	n	Conf. %	
Natural Juice 7.5 °Brix	5	65.15	4.03	91.1	41.18	4.12	98.0	768.2	0.66	98.7	4712	0.36	98.7	124.10
	20	61.23	3.91	97.6	34.10	3.94	95.7	622.5	0.68	99.2	3851	0.35	99.2	109.85
	40	53.22	3.04	98.7	30.45	3.14	99.3	541.3	0.69	97.8	2914	0.34	97.8	92.07
	60	49.25	2.73	96.1	27.22	2.75	97.5	412.1	0.73	97.8	2330	0.32	97.8	63.22
	80	38.11	2.51	95.2	24.81	2.65	94.6	298.4	0.75	98.2	1655	0.31	98.2	39.30
Conc. Juice 15.0°Brix	5	986.52	19.82	93.4	230.35	11.24	96.3	10142.2	0.75	95.1	19854	0.29	95.1	165.10
	20	929.05	16.02	94.2	171.50	10.35	95.5	9240.7	0.78	97.4	16211	0.27	97.4	132.08
	40	810.25	11.34	93.3	159.60	6.84	92.6	8014.1	0.84	96.5	12901	0.24	96.5	92.58
	60	645.81	9.75	97.4	121.30	5.71	99.4	6955.8	0.89	99.2	11087	0.23	99.2	78.45
	80	432.35	6.87	95.2	74.11	4.36	96.1	4379.4	0.91	97.4	8744	0.21	97.4	56.03
Conc. Juice 22.5°Brix	5	1720.0	38.11	96.1	458.20	17.86	99.3	17655.3	0.91	97.3	34210	0.23	97.3	198.10
	20	1497.6	31.15	97.0	407.64	13.55	99.4	15892.1	0.93	99.9	29100	0.22	99.9	184.12
	40	1105.8	29.21	93.8	325.66	10.79	93.2	14042.0	0.94	98.7	24526	0.21	98.7	129.82
	60	865.3	22.37	94.2	289.04	8.31	96.8	12125.5	0.94	99.8	21885	0.21	99.8	81.08
	80	516.2	17.44	98.7	196.55	5.85	94.3	10088.4	0.98	98.7	19650	0.20	98.7	42.13
Conc. Juice 30.0°Brix	5	2878.6	54.80	99.0	583.41	38.80	96.1	25150.5	0.99	90.4	59481	0.19	90.4	278.74
	20	2014.8	42.98	96.5	469.48	32.15	91.8	23447.2	0.99	97.2	48550	0.17	97.2	254.95
	40	1523.2	39.82	94.3	388.34	24.32	99.3	21044.2	1.01	98.7	40125	0.16	98.7	205.17
	60	992.8	32.08	92.1	324.54	18.17	95.2	19706.3	1.02	99.8	34250	0.16	99.8	174.50
	80	629.9	23.24	97.6	281.27	15.82	93.9	14255.1	1.03	99.1	31092	0.14	99.1	111.84

Where: (η): Plastic Viscosity (mPa.s) — 10 RPM viscosity (mPa.s). — (k): Consistency index ($mPa.S^n$).

(τ_o): Yield Stress (N/m^2) — (N_1): Shear sensitivity factor — (n): FLow index (dimensionless).

The thixotropy (Pa.s) values increases with increasing total soluble solids and decreasing temperature. With the increase of temperature , shear stress decreases, this indicates that it will show less apparent viscosity with the increase of temperature. These results are in agreement with those obtained by Ramos and Ibarz (1998), Singh and Eipeson (2000), El-Mansy *et al.*, (2000 a,b) , Sharoba (2004), and Nindo *et al.*, (2005)

Effect of treatment by Rohament MAX and Pectinex™ enzymes on rheological behavior of strawberry juice and its concentrates:

1- Rohament MAX

Strawberry juice has a high viscosity and the risk of jellification if concentrated up to 30 °Brix may cause problems; which can be overcome by using small amounts of pectolytic enzymes. Rohament MAX is a special enzyme preparation which contains mainly the specific pectintranseliminase (endo pectin lyase activity) used to lower the viscosity of strawberry juice with different total soluble solids. A very limited break down of pectins is carried out, just sufficient to reduce the amount of soluble pectins and lower the viscosity without attacking the cloud-stability insoluble pectin in order to lose cloud stability.

The decrease in viscosity of strawberry juice and its concentrates (7.5, 15, 22.5, and 30 °Brix) treated with different dosages (300 and 600 ppm) of Rohament MAX enzyme are given in Tables (3-4). From the obtained results it can be concluded that the Rohament MAX enzyme was the most effective in reducing the viscosity of strawberry juice at different total soluble solids.

In general, the consistency index values (k) of strawberry juice at different total soluble solids decreased with increasing enzyme dosage. In the same time the consistency index values (k) of strawberry juice at different total soluble solids decreased with increasing temperature. The consistency index (k) values were 4712, 4012 and 3215 mPa.s^n for strawberry juice of 7.5 °Brix treated by Rohament MAX enzyme concentration of 0, 300 and 600 ppm, respectively, at 5°C. The (k) values of strawberry juice of 30°Brix treated by Rohament MAX enzyme dosage of 0, 300 and 600 ppm at 80°C were 31092, 22300 and 10022 mPa.s^n, respectively. The effective and rapid reduction of viscosity of strawberry juice at different total soluble solids was obtained at dosage 600 ppm. Rohament MAX. The reduction in consistency index values (k) was due to reduction of pulp content and in turn was due to the action of pectintranseliminase. The Bingham & Casson plastic viscosity and yield stress, 10 RPM viscosity (mPa.s), consistency index and flow index (n), generally, decreased with increasing enzyme dosage. These results were in agreement with those obtained by Brekke *et al.* (1986), Crandall *et al.* (1990), Crandall and Davis (1991), Beresovsky *et al.* (1995), Abd El-Salam,. (1999) and Sharoba (1999) who reported that the pectolytic enzymes reduce the viscosity of juices and purees. This simply means that increasing concentration of enzymes increased viscosity reduction. As expected , the enzymatic extraction results in considerable degradation of the pectin fraction, thereby resulting in a moderate lower viscosity and individual intact cells, Siliha and Gierschner (1994) and Abd El-Salam (1999). The thixotropy values (Pa.s) increased with increasing enzyme dosage, the thixotropy values were 278.74, 322.13 and 368.44 Pa.s^{-1} for strawberry juice 30 °Brix treated by Rohament MAX enzyme concentration of 0, 300 and 600 ppm at 5°C.

respectively. This was probably due to an increase in the divalent cation crosslinking with pectin following Rohament MAX activity (Brekke *et al.*, 1986).

2- Pectinex™

The second chosen enzyme is Pectinex™ which is a very good capable of breaking down pectic substances in fruits and vegetables. Strawberry juice treated with different concentrate (0, 300 and 600 ppm) by Pectinex™ enzyme and concentrated to different soluble solids (7.5, 15, 22.5, and 30 °Brix) and the rheological behavior for those juices are given in Tables (5-6). The results give similar trend of Rohament MAX enzyme. The viscosity and rheological parameters (The Bingham & Casson plastic viscosity and yield stress, 10 RPM viscosity, consistency index and flow index) decreased with increasing enzyme concentrate and temperature.

The consistency index values (k) were 3851, 3403 and 2817 mPa.s^n for Strawberry juice of 7.5 °Brix treated by Pectinex™ enzyme concentration of 0, 300 and 600 ppm at 20°C, respectively. Also (k) values of concentrated strawberry of 30 °Brix at 80°C were 31092, 18280 and 11379 mPa.s^n, respectively. In the same time the 10 RPM Viscosity values decreased with increasing enzyme concentrate, while the thixtropy values increased. These results agree with Abd El-Salam (1999) and Sharoba (1999).

From data in Tables (3 to 6) it appears that the Rohament MAX enzyme was more effective in reducing viscosity and rheological parameters than Pectinex™ enzyme at different concentrations and temperatures. However dosage of 600 ppm it is the best concentration for treatment strawberry juice at different total soluble solids in the both enzymes.

Effect of temperature on flow behavior of strawberry juice at different total soluble solids treated by enzymes:

The viscosity is dependent upon the intermolecular distances. As the temperature increases, the intermolecular distances increase and therefore the viscosity will decrease for these main reasons. The viscosity is a function of temperature and dissolved solid concentration (Bayindirli, 1992).

The Arrhenius equation to a great extent explains the relationship between temperature and viscosity (Özilgen and Bayindirli (1992) and Essa (2002). Results presented in Table (7) showed the variation in viscosity with temperature described by an Arrhenius-type. The activation energy (Ea) of untreated strawberry juices was 19676.74, 6724.95, 7725.37 and 3864.51 J/mol. for concentrations of 7.5, 15, 22.5, and 30 °Brix and η_∞ were 1.1637, 6.4060, 6.4239 and 8.4176 mPa.s, respectively. The η_∞ factors increased with increasing total soluble solids.

Strawberry concentrates have relatively low sugar and high pulp contents and therefore have low Ea. Data in Table (7) show that increasing total soluble solids of strawberry juice increased the magnitude of Ea decrease.

Table (3): Rheological parameters of strawberry juices treated by 300 ppm Max enzyme.

Treatments	Temp. (°C)	Parameters for different models												Thixotropy ($Pa.s^{-1}$)
		Bingham			Casson			IPC paste			Power law			
		$\eta_{(B)}$	$\tau_{o(B)}$	Conf. %	$\eta_{(C)}$	$\tau_{o(C)}$	Conf. %	10 RPM visc.	N1	Conf. %	K	n	Conf. %	
Natural Juice 7.5°Brix with 300 ppm Max	5	63.15	3.93	90.0	33.40	3.83	93.1	537.2	0.65	95.5	4012	0.35	95.5	132.01
	20	53.03	3.33	97.0	30.11	3.45	95.7	465.8	0.72	93.7	3144	0.34	93.7	112.02
	40	39.56	2.81	91.7	25.60	2.81	93.7	400.9	0.83	90.2	2851	0.32	90.2	87.23
	60	17.74	1.92	96.4	23.24	2.29	96.1	322.7	0.86	93.5	2013	0.30	93.5	54.12
	80	15.03	1.40	98.1	18.05	2.21	93.8	233.9	0.87	97.4	1066	0.27	97.4	43.11
Conc. Juice 15.0°Brix with 300 ppm Max	5	589.5	11.30	91.1	219.01	9.42	92.3	5399	0.75	92.8	12680	0.25	92.8	172.36
	20	465.5	9.58	94.2	182.90	8.57	91.8	4379	0.84	98.6	11785	0.25	98.6	141.14
	40	299.9	5.46	91.0	104.33	4.58	92.6	3303	0.85	91.4	9935	0.23	91.4	104.21
	60	213.3	5.40	97.6	72.04	3.98	98.2	2834	0.89	99.8	7596	0.21	99.8	85.20
	80	90.7	3.59	97.2	34.90	3.25	97.6	2637	0.91	97.3	6137	0.19	97.3	52.89
Conc. Juice 22.5°Brix with 300 ppm Max	5	891.4	22.15	95.9	301.46	16.20	95.6	12632	0.88	95.3	22350	0.23	95.3	219.78
	20	732.2	19.91	97.9	236.12	9.71	97.9	10580	0.91	97.9	19101	0.22	97.9	201.10
	40	605.7	17.90	96.7	197.69	8.19	96.9	8321.1	0.91	96.8	18019	0.18	96.8	152.31
	60	510.6	15.35	96.7	135.50	7.38	92.1	5640.6	0.98	99.6	14280	0.17	99.6	87.09
	80	284.7	14.29	97.3	80.50	3.80	98.2	3982.9	0.99	98.3	9855	0.15	98.3	51.08
Conc. Juice 30.0°Brix with 300 ppm Max	5	937.1	42.43	94.4	396.24	39.0	90.4	18706	0.92	95.4	43449	0.17	95.4	322.13
	20	818.9	29.24	91.2	354.11	29.3	91.2	15360	0.93	97.2	39650	0.14	97.2	305.88
	40	703.1	23.81	96.3	284.33	22.0	94.2	12841	0.99	96.5	28463	0.12	96.5	271.50
	60	629.9	14.40	98.9	251.84	14.3	90.9	11328	0.99	98.9	24237	0.11	98.9	189.12
	80	407.8	14.33	97.2	204.57	14.1	95.3	10319	1.01	99.3	22300	0.11	99.3	104.17

Where: (η): Plastic Viscosity (mPa.S)   10 RPM viscosity (mPa.S).   (k): Consistency index ($mPa.S^n$).

(τ_o): Yield Stress(N/m^2)   (N_1): Shear sensitivity factor   (n): FLow index (dimensionless).

Table (4): Rheological parameters of strawberry juices treated by 600 ppm Max enzyme.

Treatments	Temp. (°C)	Parameters for different models												Thixotropy ($Pa.s^{-1}$)
		Bingham			Casson			IPC paste			Power law			
		$\eta_{(B)}$	$\tau_{o(B)}$	Conf. %	$\eta_{(C)}$	$\tau_{o(C)}$	Conf. %	10 RPM visc.	N1	Conf. %	K	n	Conf. %	
Natural Juice7.5 °Brix with 600 ppm Max	5	52.40	3.24	91.5	27.50	3.26	90.0	415.1	0.67	92.2	3215	0.33	92.2	139.12
	20	37.04	2.55	95.7	21.06	2.83	97.5	345.3	0.69	99.5	2963	0.31	99.5	92.05
	40	27.02	2.03	93.6	18.61	2.09	95.7	299.8	0.72	96.1	2558	0.28	96.1	87.41
	60	14.70	1.62	95.1	14.66	1.41	93.9	234.4	0.74	92.2	1760	0.26	92.2	35.06
	80	11.92	1.32	98.1	11.06	1.20	95.0	199.3	0.75	96.4	1248	0.22	96.4	27.80
Conc. Juice 15.0°Brix with 600 ppm Max	5	516.5	8.84	93.9	216.4	8.23	93.7	5454	0.76	95.3	10101	0.29	95.3	162.14
	20	423.7	6.75	92.5	174.2	5.82	99.0	4302	0.79	98.8	9969	0.22	98.8	147.27
	40	310.8	5.28	92.9	107.3	4.41	98.7	3167	0.81	99.3	8071	0.21	99.3	94.04
	60	113.0	4.90	94.6	69.97	3.70	95.4	2618	0.86	96.2	6138	0.19	96.2	68.86
	80	78.4	3.25	91.4	49.32	3.01	92.2	1985	0.88	94.3	5894	0.19	94.3	60.23
Conc. Juice 22.5°Brix with 600 ppm Max	5	791.3	19.80	95.5	299.3	9.04	97.2	10245	0.78	94.9	18907	0.24	94.9	248.55
	20	614.5	18.53	97.4	220.6	7.33	98.8	8950	0.78	94.4	16580	0.21	94.4	218.68
	40	475.8	17.90	97.2	138.1	5.79	93.2	6263	0.84	95.9	12622	0.21	95.9	142.25
	60	346.2	15.04	93.1	98.7	4.19	94.7	5395	0.87	98.1	11109	0.20	98.1	92.11
	80	222.6	13.94	92.9	51.0	3.74	92.0	3598	0.88	94.2	8030	0.19	94.2	57.14
Conc. Juice 30.0°Brix with 300 ppm Max	5	815.0	38.00	96.9	287.3	22.35	96.6	14552	0.87	94.7	35620	0.17	94.7	368.44
	20	696.1	27.62	91.2	211.5	17.70	93.1	12333	0.92	96.0	28465	0.16	96.0	307.44
	40	543.9	22.27	93.5	184.7	16.35	94.3	9870	0.92	98.8	19947	0.13	98.8	264.59
	60	433.9	19.30	92.6	145.0	15.89	93.9	8597	0.93	98.2	16875	0.13	98.2	183.04
	80	401.4	13.67	94.8	107.5	12.37	96.4	6320	0.94	96.4	10022	0.12	96.4	112.00

Where: (η):Plastic Viscosity (mPa.S) — 10 RPM viscosity (mPa.S). — (k): Consistency index ($mPa.S^n$).

(τ_o): Yield Stress(N/m^2) — (N_1): Shear sensitivity factor — (n): FLow index (dimensionless).

Table (5): Rheological parameters of strawberry juices treated by 300 ppm Pectinex enzyme.

Treatments	Temp. (°C)	Parameters for different models: Bingham			Casson			IPC paste			Power law			Thixotropy ($Pa.s^{-1}$)
		$\eta_{(B)}$	$\tau_{o(B)}$	Conf. %	$\eta_{(C)}$	$\tau_{o(C)}$	Conf. %	10 RPM visc.	N1	Conf. %	K	n	Conf. %	
Natural Juice 7.5°Brix with 300 ppm Pectinex	5	57.45	3.94	91.2	39.23	3.95	93.9	595.1	0.65	96.8	4216	0.36	96.8	136.13
	20	55.64	3.62	90.0	31.89	3.45	92.2	437.8	0.69	93.9	3403	0.34	93.9	107.44
	40	47.16	2.64	97.9	27.45	2.88	98.0	390.5	0.73	98.5	2924	0.33	98.5	100.05
	60	39.74	1.98	90.1	26.50	2.45	92.2	332.4	0.75	93.8	2089	0.32	93.8	92.37
	80	27.31	1.38	91.3	25.73	2.39	96.0	258.0	0.77	91.6	1306	0.30	91.6	84.12
Conc.Juice 15.0°Brix with 300 ppm Pectinex	5	836.5	9.48	94.7	217.52	10.23	92.7	5564	0.70	96.6	13562	0.30	96.6	171.00
	20	643.1	7.55	97.2	177.73	7.48	97.8	4412	0.72	94.2	12041	0.28	94.2	155.48
	40	245.0	6.62	97.7	115.30	5.50	97.5	3818	0.88	98.8	8506	0.25	98.8	117.13
	60	183.6	5.85	97.6	95.61	5.31	92.0	3117	0.89	93.7	6319	0.23	93.7	108.44
	80	140.1	4.98	98.3	45.24	5.09	90.6	2840	0.89	92.1	6762	0.22	92.1	88.23
Conc.Juice 22.5°Brix with 300 ppm Pectinex	5	971.3	17.00	91.2	318.04	17.08	93.9	14630	0.78	93.5	25311	0.22	93.5	287.83
	20	895.4	16.23	94.0	262.29	12.51	96.3	10457	0.83	92.9	20165	0.21	92.9	271.05
	40	620.3	15.30	93.3	226.87	10.05	93.4	8517	0.92	92.5	16664	0.18	92.5	224.93
	60	606.0	14.75	90.4	195.82	8.44	91.1	6351	0.92	92.6	14729	0.18	92.6	184.11
	80	203.8	14.70	95.7	103.51	7.43	96.3	4979	0.94	96.4	11724	0.16	96.4	106.13
Conc.Juice 30.0°Brix with 300 ppm Pectinex	5	1144.7	42.64	91.4	411.58	38.78	98.3	20755	0.91	92.4	51240	0.20	92.4	356.02
	20	1011.0	36.89	96.8	390.18	31.75	96.7	17420	0.91	96.8	42364	0.19	96.8	327.17
	40	845.6	36.13	96.2	315.20	26.88	97.4	15550	0.98	94.9	34419	0.19	94.9	278.55
	60	772.2	22.63	96.3	296.04	20.82	97.5	13739	1.02	99.7	22416	0.18	99.7	190.74
	80	647.5	18.00	98.2	236.43	16.40	91.5	11948	1.02	94.5	18280	0.16	94.5	174.01

Where: (η):Plastic Viscosity (mPa.s) 10 RPM viscosity (mPa.s). (k): Consistency index ($mPa.s^n$).

(τ_o): Yield Stress(N/m^2) (N_1): Shear sensitivity factor (n): FLow index (dimensionless).

Table (6): Rheological parameters of strawberry juices treated by 600 ppm Pectinex enzyme.

Treatments	Temp. (°C)	Parameters for different models												Thixotropy ($Pa.s^{-1}$)
		Bingham			Casson			IPC paste			Power law			
		$\eta_{(B)}$	$\tau_{o(B)}$	Conf. %	$\eta_{(C)}$	$\tau_{o(C)}$	Conf. %	10 RPM visc.	N1	Conf. %	K	n	Conf. %	
Natural Juice 7.5 °Brix with 600 ppm Pectinex	5	55.10	3.50	97.3	30.10	3.52	97.5	464.9	0.68	97.9	364.9	0.33	97.9	144.23
	20	42.50	2.86	96.9	22.39	2.44	95.8	349.4	0.74	96.7	2817	0.32	96.7	113.05
	40	31.34	2.33	97.9	18.50	2.37	94.4	270.5	0.75	97.6	2391	0.32	97.6	101.47
	60	24.89	1.57	93.3	15.17	2.01	94.9	217.5	0.78	94.6	1841	0.29	94.6	98.25
	80	18.35	1.28	91.2	12.07	1.31	95.1	192.4	0.80	91.2	1212	0.25	91.2	87.41
Conc. Juice 15.0°Brix with 600 ppm Pectinex	5	808.4	8.90	96.5	202.1	9.70	94.6	5034	0.71	91.1	10373	0.28	91.1	174.89
	20	511.1	6.50	93.3	169.3	6.32	95.1	4090	0.72	93.4	9637	0.28	93.4	159.08
	40	357.2	5.91	93.7	106.7	5.38	93.5	3143	0.83	94.0	7295	0.27	94.0	122.37
	60	157.2	5.36	97.0	68.4	4.57	98.2	2363	0.88	99.7	5662	0.24	99.7	107.70
	80	93.8	3.73	98.2	39.0	3.12	91.7	1860	0.89	91.8	4040	0.25	91.8	95.12
Conc. Juice 22.0°Brix with 600 ppm Pectinex	5	949.6	16.80	95.3	257.0	14.17	92.1	10855	0.75	96.1	21629	0.23	96.1	305.82
	20	784.8	15.30	92.8	218.6	11.88	97.5	8294	0.78	99.5	16952	0.22	99.5	288.37
	40	509.8	13.40	91.9	142.6	9.29	93.1	6128	0.91	92.8	14124	0.20	92.8	241.22
	60	341.7	11.87	91.3	112.2	6.93	92.7	5301	0.91	93.2	9901	0.19	93.2	183.01
	80	202.0	10.50	95.7	50.5	5.25	97.3	3889	0.98	98.5	8979	0.17	98.5	108.36
Conc.Juice 30.0°Brix with 600 ppm Pectinex	5	912.7	42.04	95.8	289.2	35.35	96.8	15423	0.89	96.9	44014	0.18	96.9	394.11
	20	721.9	35.61	91.9	194.2	25.71	92.5	13015	0.92	92.0	32209	0.18	92.0	328.54
	40	682.5	26.37	91.1	146.0	20.54	92.5	10138	0.95	94.4	21019	0.14	94.4	284.17
	60	413.2	19.62	95.8	119.3	18.32	99.3	8850	0.97	93.7	17929	0.13	93.7	201.85
	80	361.6	16.41	96.8	86.9	13.80	98.0	6983	0.99	99.4	11379	0.10	99.4	174.92

Where: (η):Plastic Viscosity (mPa.s) 10 RPM viscosity (mPa.s). (k): Consistency index ($mPa.s^n$).
(τ_o): Yield Stress(N/m^2) (N_1): Shear sensitivity factor (n): FLow index (dimensionless).

Table (7): Arrhenius-Type Constants Relating the Effect of Temperature* and Viscosity at 10 RPM on Strawberry Juice at Different Total Soluble Solids Treated By Enzymes.

Enzyme Type	Enzyme Concentration (ppm)	Total Soluble Solid (°Brix)	Coefficient Correlation (r)	E_a (J/mol.)	η_∞ (mPa.s)
Control	untreated	7.5	0.909	19676.74	1.1637
		15.0	0.984	6724.95	6.4060
		22.5	0.979	7725.37	6.4239
		30.0	0.986	3864.51	8.4176
Pectinex	300	7.5	0.959	11215.59	1.0391
		15.0	0.995	8951.68	4.6627
		22.5	0.970	10885.52	4.1574
		30.0	0.984	14061.47	3.4573
	600	7.5	0.972	11622.97	0.8374
		15.0	0.975	14297.59	2.8019
		22.5	0.949	11840.80	4.1914
		30.0	0.981	7211.15	6.9490
Max	300	7.5	0.980	11322.01	1.2032
		15.0	0.966	10415.78	4.0945
		22.5	0.956	11899.00	4.1078
		30.0	0.968	12363.75	4.4441
	600	7.5	0.993	7040.88	3.2199
		15.0	0.974	7185.38	5.5122
		22.5	0.967	6395.05	5.7929
		30.0	0.982	8743.83	5.3763

* *Temperature range for E_a (5-80°C)*

In the same time the Ea values were 11622.97, 14297.59, 11840.80 and 7211.15 J/mol. for strawberry juice treated by 600 ppm Pectinex™ enzyme at 7.5, 15, 22.5, and 30 °Brix, respectively. The η_∞ values increased with increasing total soluble solids. The η_∞ values were 0.8374, 2.8019, 4.1914 and 6.9490 (mPa.s) for the same samples.

These results are in agreement with those obtained by Essa (2002) who reported that increasing suspended solids is accompanied by decreasing Ea. The same trend was observed by the Rohament MAX treated samples. From the Arrhenius plots of these samples coefficient of correlation (r) values were greater than 0.909.

Sensory evaluation of preparation strawberry juices:

The acceptability of the strawberry juice treated and un-treated by enzymes, for color, odor, taste, texture (mouth feel) and overall acceptability was evaluated.

As shown in Table (8) significant differences were noticed for texture (mouth feel) and color. On the other hand, the scores showed no significant differences in odor, taste and overall acceptability. The significant differences in the scores were found only for texture (mouth feel). These results depend on the effect of enzymes.

Table (8): Sensory properties of strawberry juice at different total soluble solids treated by enzymes.

A. Color

Juice con.	Treatments					Average
	Untreated	300P	600P	300M	600M	
7.5°Brix	23.92±0.26	23.42±0.31	23.00±0.25	23.58±0.40	22.67±0.33	23.32^{a}±0.15
15.0 °Brix	23.58±0.31	23.00±0.33	22.58±0.36	22.83±0.41	21.92±0.29	22.78^{b}±0.16
22.5 °Brix	22.25±0.33	21.25±0.18	21.00±0.28	21.33±0.26	21.25±0.22	21.42^{b}±0.12
30.0 °Brix	21.67±0.36	21.25±0.35	20.92±0.34	20.92±0.29	20.25±0.30	21.00^{c}±0.15
Average	22.85^{a} ±0.20	22.23^{b} ±0.20	21.88^{bc} ±0.20	22.17^{b} ±0.23	21.52^{c} ±0.19	
LSD (°Brix)	0.39					
LSD (Treat)	0.43					
LSD (Treat Within Brix)	0.86					

B. Odor

Juice con.	Untreated	300P	600P	300M	600M	Average
7.5°Brix	23.42±0.43	23.50±0. 34	23.50±0.40	23.42±0.36	23.50±0.45	23.47^{a}±0.17
15.0 °Brix	23.00±0.49	22.67±0.31	22.67±0.26	22.83±0.37	22.17±0.42	22.67^{b}±0.17
22.5 °Brix	21.75±0.30	21.75±0.18	21.17±0.24	21.25±0.28	21.17±0.30	21.42^{c}±0.12
30.0 °Brix	20.92±0.31	20.50±0.38	20.08±0.47	20.58±0.36	20.08±0.53	20.43^{d}±0.19
Average	22.27^{a}±0.24	22.10^{a}±0.22	21.85^{a}±0.26	22.02^{a}±0.24	21.73^{b}±0.28	
LSD (°Brix)	0.46					
LSD (Treat)	0.51					
LSD (Treat Within Brix)	1.02					

C.. Taste

Juice con.	Untreated	300P	600P	300M	600M	Average
7.5°Brix	23.83±0.32	23.25±0. 25	23.67±0.19	23.33±0.26	24.00±0.28	23.62^{a} ±0.12
15.0 °Brix	23.17±0.56	23.00±0.30	23.08±0.34	22.92±0.34	22.50±0.53	22.93^{b} ±0.19
22.5 °Brix	21.58±0.36	21.17±0.30	20.17±0.32	21.08±0.23	20.92±0.42	20.98^{c} ±0.15
30.0 °Brix	20.33±0.43	19.83±0.34	19.67±0.28	20.00±0.37	20.08±0.47	19.98^{d} ±0.17
Average	22.23^{a} ±0.29	21.81^{a}±0.25	21.65^{b}±0.29	21.83^{a}±0.25	21.88^{a}±0.30	
LSD (°Brix)	0.44					
LSD (Treat)	0.49					
LSD (Treat Within Brix)	0.99					

D. Texture

Juice con.	Untreated	300P	600P	300M	600M	Average
7.5°Brix	24.58±0.15	23.83±0.32	23.25±0.18	23.67±0.19	23.17±0.17	23.70^{a} ±0.11
15.0 °Brix	23.75±0.25	22.58±0.50	22.00±0.56	23.25±0.33	21.33±0.50	22.60^{b} ±0.22
22.5 °Brix	22.00±0.33	21.58±0.31	21.17±0.24	21.50±0.44	21.17±0.34	21.50^{c} ±0.15
30.0 °Brix	21.92±0.29	21.08±0.34	20.17±0.46	20.75±0.22	20.17±0.32	20.80^{d} ±0.17
Average	23.06^{a}±0.21	22.27^{b}±0.24	21.65^{c}±0.25	22.29^{b}±0.23	21.50^{c}±0.23	
LSD (°Brix)	0.42					
LSD (Treat)	0.47					
LSD (Treat Within Brix)	0.95					

E. Over all acceptability

Juice con.	Untreated	300P	600P	300M	600M	Average
7.5°Brix	94.83±0.53	94.25±0.37	94.08±0.36	94.92±0.51	95.08±0.40	94.63^{a} ±0.20
15.0 °Brix	93.58±0.47	93.42±0.68	92.67±0.74	93.83±0.66	93.00±0.76	93.30^{b} ±0.29
22.5 °Brix	91.92±0.34	91.25±0.41	91.08±0.43	91.58±0.43	91.17±0.51	91.40^{c} ±0.19
30.0 °Brix	89.50±0.48	88.42±0.75	87.75±0.98	88.83±0.74	88.17±0.63	88.53^{d} ±0.33
Average	92.46^{a}±0.37	91.83^{a}±0.43	91.40^{b}±0.47	92.29^{a}±0.45	91.85^{a}±0.47	
LSD (°Brix)	0.72					
LSD (Treat)	0.81					
LSD (Treat Within Brix)	1.62					

* *M* (Rohament MAX) *P* (Pectinex™)

Values represent of 12 panelists (Mean ± S.E.)

a, b There is no significant difference ($p \geq 0.05$) between any two averages of different treatment, or different juice Brix have the same superscripts, within the same acceptaptability attribute

Analysis of variance indicated that there was significant difference ($P< 0.05$) in the sensory evaluation (color, odor, taste, texture (mouth feel) and overall acceptability) between the two enzymes concentrations (300 and 600 ppm) on strawberry juices at different total soluble solids. It must be mentioned here that evaluated samples were offered to the panelists after adjust their to concentration to 7.5 °Brix.

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تأثير بعض المعاملات الأنزيمية على السلوك الريولوجى لعصير الفراولة ومركزاته

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نظرا لأن الخواص الريولوجية للمواد الغذائية التى تتبع الموائع هامة جدا فى حل الكثير من مشاكل التصنيع الغذائى فقد تم قياس السلوك الريولوجي لعصير الفراولة الطبيعى والعصير المركز بتركيزات (١٥-٢٢,٥-٣٠ °بركس) علي معدل إجهاد بين (٠,١ – ١٠٠ ثانية$^{-1}$) وعلي مدي من درجات الحرارة (٥ ، ٢٠، ٤٠، ٦٠ و ٨٠ °م) و تم أيضا معاملة العصير باستخدام أنزيمي مكس وبكتينكس باستخدام تركيزين من الأنزيمين ٣٠٠ و ٦٠٠ جزء فى المليون للعصير الطبيعى وتم إجراء التركيز بواسطة جهاز روترى إلى ١٥- ٢٢,٥- ٣٠ ° بركس وتم قياس الخصائص الريولوجية علي نفس المدى من درجات الحرارة ومعدل القص باستخدام جهاز روميتر بروكفيلد الدورانى +RV II.

وأوضحت النتائج المتحصل عليها إن عصير ومركزات الفراولة المعاملة بالأنزيم والغير معاملة من المواد الغير نيوتينية وتسلك السلوك الشبه بلاستيكي مع إجهاد خضوع. وتم حساب الثوابت الريولوجية باستخدام المعادلات الرياضية الريولوجية وخاصة موديلات بنجهام وكيزون وأى بى سى بست وقانون الأس ومنهما تم حساب دليل القوام ومعامل القوام واللزوجة الظاهرية وإجهاد الخضوع واللزوجة عند معدل دوران ١٠ لفات فى الدقيقة وتم حساب قيمة الثيكستروبي. وكانت النتائج المتحصل عليها تدل على أن اللزوجة للعصير تزداد بزيادة المواد الصلبة الذائبة، وتنخفض بارتفاع درجة الحرارة. ومن ناحية أخرى كانت لزوجة العصير ومركزاته تنخفض بالمعاملة بالأنزيم وأن تركيز ٦٠٠ جزء فى المليون كان أكثر تأثيرا علي اللزوجة والخواص الريولوجية فى كلا الأنزيمين وأن أنزيم مكس كان الأكثر تأثيرا عند التركيزين المستخدمين.

وانخفضت جميع الثوابت انخفاضا واضحا باستخدام الأنزيمين وعلى العكس من ذلك كانت قيم الثيكستروبي تزداد بالمعاملة بالأنزيم. ونتيجة لانخفاض اللزوجة تقل تكلفة تركيز العصائر وتقل درجات الحرارة المستخدمة للتركيز والبسترة والتسخين وتقل قدرة المواتير اللازمة لضخ ونقل العصائر داخل مصانع الأغذية. وتم إيجاد العلاقة بين درجة الحرارة واللزوجة باستخدام معادلة أرهينيوس ومن خلالها تم حساب طاقة التنشيط ومعامل اللزوجة الأمبيرالى.

تم أيضا دراسة التركيب الكيماوي والطبيعي لعصير الفراولة ، كما تم أيضا إجراء التقييم الحسي لجميع التحضيرات العصيرية المعاملة والغير معاملة بالإنزيم.