RESULTS & DISCUSSION

5. RESULTS AND DISCUSSION

Tomato and tomato products

5.1. Chemical composition and physical properties:

Technological characteristics, such as chemical composition, rheological properties, physical properties and sensory properties play an important role in the formation of the processing steps, which are necessary for the production of tomato ketchup. This part deals with some of these aspects, in order to obtain some useful data for the differentiation between the tested tomato ketchup; Lidl, Kraft, Werder, Heinz and Reichelt from Germany and Americana, Heinz and GSF from Egypt. These kinds represent the most available tomato ketchup that used in Germany and Egypt. Results recorded in Table (5.1) show some chemical and physical properties of the obtained tomato ketchup.

5.1.1. Chemical composition and physical properties of some commercial tomato ketchups:

5.1.1.1. Total solids, Moisture and Ash:

The solids content is an important factor in the production of tomato ketchup. It is well known that the higher the total solids the better will be the quality of the end product. As shown in Table (5.1) there is a slight difference in the total solids content between ketchups samples. The Americana Egypt ketchup had the highest total solids content being 33.35 %, while the Kraft ketchup showed the lowest content being 24.36 %. The results were in agreement with those obtained by **Bottiglieri *et al.* (1991) and Canovas and Peleg (1983)** who found the total solids in tomato ketchup (Heinz) 32.2 % and 34.4 % for tomato ketchup (Stop and Shop). Also the same data of Table (5.1) represent, the Ash content of tomato ketchup. The lowest content being 2.19 % for Heinz Egypt ketchup while the higher content was 3.94 % for Heinz ketchup. The results were in agreement with those obtained by **FCRF (1990)** who found the Ash content 3.4, 2.8 and 4.2 for tomato ketchup.

5.1.1.2. Titratable acidity and pH Value:

pH and acidity are important factors in fluencing on the quality of tomato ketchup. The pH values were ranged between 3.40 for Heinz and 3.84 for Werder. The obtained values were in accordance with that obtained by **Upasana and Bains (1987)** who found that pH value for tomato ketchup ranged between 3.55 to 3.87 and **Porretta and Birzi (1995)** who found that pH value for tomato ketchup 3.78 and 3.76. The acidity values obtained from the tested ketchups were ranged between 0.83 % to 1.64 % for Werder and Heinz, respectively. Also the results were in agreement with those obtained by **Porretta and Birzi (1995)**.

Table (5.1) : Some Chemical and Physical Properties of Tomato Ketchup

Components	Lidl	Kraft	Werder	Heinz	Reichelt	Americana Egypt	Heinz Egypt	G S F Egypt
Total Solids %	28.26 ± 0.040	24.36 ± 0.075	24.38 ± 0.190	32.49 ± 0.100	26.21 ± 0.880	33.35 ± 0.142	31.31 ± 0.022	32.54 ± 0.087
Moisture %	71.58 ± 0.040	75.64 ± 0.075	75.62 ± 0.190	67.51 ± 0.100	73.79 ± 0.880	66.65 ± 0.142	68.69 ± 0.022	67.46 ± 0.087
Ash %	3.610 ± 0.001	3.060 ± 0.001	2.548 ± 0.0001	3.940 ± 0.002	3.374 ± 0.0008	2.938 ± 0.005	2.186 ± 0.0026	2.420 ± 0.006
Ascorbic acid (mg/100g)	27.14 ± 0.137	26.97 ± 0.308	23.39 ± 0.095	21.30 ± 0.008	24.12 ± 0.510	28.99 ± 0.063	27.11 ± 0.041	29.89 ± 0.033
pH values	3.663 ± 0.003	3.713 ± 0.003	3.843 ± 0.003	3.403 ± 0.003	3.413 ± 0.003	3.476 ± 0.003	3.683 ± 0.003	3.713 ± 0.012
Titratable acidity %(as anhydrous Lactic acid)	1.407 ± 0.066	1.283 ± 0.006	0.829 ± 0.004	1.640 ± 0.009	1.619 ± 0.031	1.544 ± 0.0001	1.606 ± 0.0005	1.559 ± 0.0017
Starch%	0.831 ± 0.002	0.727 ± 0.002	3.246 ± 0.004	0.593 ± 0.011	3.924 ± 0.017	4.513 ± 0.015	0.863 ± 0.012	2.391 ± 0.013
Total Sugars %	15.5460 ± 0.017	11.9748 ± 0.015	12.0460 ± 0.104	16.9706 ± 0.089	14.2137 ± 0.071	17.8370 ± 0.048	15.3846 ± 0.110	17.7929 ± 0.127
Reducing Sugars %	10.2731 ± 0.011	8.3590 ± 0.017	8.1996 ± 0.012	12.5689 ± 0.037	9.1154 ± 0.044	11.9992 ± 0.025	10.1496 ± 0.042	12.6050 ± 0.038
Non Reducing Sugars %	5.2729	3.6158	3.8464	4.4017	5.0983	5.8378	5.2350	5.1879
Total Pectic Substances %	6.6104	5.9242	5.8246	7.9330	5.5262	6.4849	6.0108	6.8045
Water Soluble Pectin %	0.9356 ± 0.013	1.1506 ± 0.063	1.1536 ± 0.017	1.6482 ± 0.024	1.0928 ± 0.015	1.2820 ± 0.018	1.1243 ± 0.016	1.4741 ± 0.013
Ammonium Oxalate Soluble Pectin %	4.1036 ± 0.022	3.5478 ± 0.025	3.2971 ± 0.038	4.4624 ± 0.021	3.2696 ± 0.052	3.4246 ± 0.037	3.7264 ± 0.041	3.8682 ± 0.036
Acid Soluble Pectin %	1.5712 ± 0.009	1.2258 ± 0.016	1.3739 ± 0.021	1.8224 ± 0.015	1.1638 ± 0.018	1.7783 ± 0.014	1.1601 ± 0.023	1.4622 ± 0.019
Pulp Content (V/V) %	56.53 ± 0.546	58.87 ± 1.922	80.46 ± 0.067	71.13 ± 1.235	63.80 ± 0.529	74.47 ± 0.176	76.47 ± 0.176	66.93 ± 0.874
Colour Index (O.D. at 420 nm)	0.867 ± 0.002	0.848 ± 0.007	0.888 ± 0.003	0.612 ± 0.002	0.819 ± 0.0003	0.912 ± 0.0005	0.953 ± 0.003	0.986 ± 0.0025
Carotenoids (mg/l)	1.415 ± 0.022	1.289 ± 0.034	1.612 ± 0.037	0.934 ± 0.056	1.053 ± 0.002	1.095 ± 0.0031	1.651 ± 0.0074	1.674 ± 0.0552
Lycopene (mg/100 g)	8.9729 ± 0.032	7.710 ± 0.011	9.137 ± 0.033	7.013 ± 0.008	8.219 ± 0.034	8.352 ± 0.0203	11.169 ± 0.020	11.249 ± 0.019
Specific heat capacity kJ/kg K	3.0674 ± 0.003	3.1873 ± 0.001	3.1867 ± 0.002	2.9517 ± 0.002	3.1321 ± 0.002	2.9278 ± 0.003	2.9848 ± 0.003	2.9503 ± 0.002
Density at temperature 5 °C (kg/m^3)	1118.64 ± 0.000	1116.21 ± 0.052	1113.28 ± 0.000	1150.42 ± 0.033	1119.27 ± 0.000	1158.58 ± 0.008	1150.93 ± 0.003	1160.67 ± 0.007
Density at temperature 30 °C (kg/m^3)	1109.64 ± 0.037	1105.25 ± 0.027	1102.42 ± 0.003	1140.45 ± 0.011	1109.69 ± 0.004	1149.52 ± 0.005	1143.39 ± 0.001	1150.75 ± 0.001

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

5.1.1.3. Ascorbic acid (vit .C):

Tomato and tomato products are considered as a good source of vit.C. The results obtained in Table (5.1) showed that the ketchup samples under investigation contained the following vit.c. levels 27.14, 26.97, 23.39, 21.30, 24.12, 28.99, 27.11 and 29.89 mg /100g for tomato ketchups, respectively. The results were in agreement with **Orzaez *et al.* (1991)** who found that vit.C. ranged between 8.11 to 60.04 mg /100 g.

5.1.1.4. Total sugars:

Sugars are one of the most important quality parameter of the tomato ketchup, because it is contribution to the flavour, quality, platability and discoloration of tomato ketchup .The data obtained in Table (5.1) showed that, the total sugar contents of the tested ketchups were within the range from 11.97 to 17.79 % for Kraft and GSF Egypt, respectively. While reducing sugar ranged from 8.36 to 12.61 % for Kraft and GSF Egypt, respectively. The obtained data were in agreement with those observed by **Person (1976), FCRF (1990) and Vitacel (2002)** who found mean values and ranges included: sucrose 9.3 and 4.2-12.7 g/100 g glucose 6.1 and 3.7-10.8 g/100 g fructose 5.7 and 3.6-11.0 g/100g.

5.1.1.5. Pectic substances and Pulp content:

Pectic substances are the main factor which greatly influence the quality, stability, process ability and viscosity of tomato ketchup. The total pectic content of ketchup were the sum of the pectin fractions extract; water extract, ammonium oxalate extract and acid extract. The obtained results presented in Table (5.1) showed that the total pectin for ketchup were 6.61, 5.92, 5.82, 7.93, 5.53, 6.48, 6.01 and 6.80 for ketchup samples under investigation, respectively. The ammonium oxalate extract was the highest, while the water soluble pectin showed the lowest content. The obtained data were in accordance with that found by **Sharoba (1999)** who found that the ammonium oxalate extract was the highest in tomato products. Pulp content also was showing the range from 80.46 V/V to 56.53 V/V for Werder and Lidl, respectively. These results were in agreement with those of **Bottiglieri *et al.* (1991).**

5.1.1.6. Color index, lycopene and carotenoid contents:

The color index (O.D. at 420nm) for ketchup were recorded between 0.61 and 0.99 for Heinz and GSF Egypt, respectively. Epidemiological studies have shown that increased consumption of fruits, including tomatoes, is associated with reduced risk of Lung and other epithelial Cancers. It has been suggested that high carotenoid levels in tomato fruits are responsible for this reduced risk **Tonucci, *et al.* (1995)** and **Stanley (2002)**. Also increased consumption of tomato and tomato products has been associated with decreased Cancer risk, one fat-soluble compound identified in tomatoes, which may be responsible for this association is lycopene, **(Djuric and Powell 2001)**. The carotenoids content presented in Table (5.1) was within the range 0.93 to 1.67 mg/l. The results were in agreement with those obtained by **Tavares and Rodriguez (1994)**. The lycopene content was ranged between 7.71 to 11.25 mg /100g). These results were in agreement with those obtained by **Wilberg and Rodriguez (1993)** and **Prokupkova and Novotna (1998)**.

5.1.1.7. Density and Specific heat Capacity:

Knowledge of the physical properties of food is fundamental in analysing the unit operations present in the food industry. The study of these food properties and their responses to process conditions are necessary because they influence the treatment received during the processing and also because they are good indicators of other properties and qualities of food. This allows a better control of both product and processing, with benefits for the producer, industry and the consumer. The transport phenomena of momentum, heat and mass can be applied with efficiency in food systems if engineering data are available (**Saravacos and Kostaropoulos, 1995**). Unfortunately such engineering properties data are scarce. Data such as density (ρ) and its variation with temperature, and specific heat capacity are very important for the food industry in general and in particular for fruit derivatives since it is necessary for the design and the optimisation of several processing operations (pumping, evaporation, heat transfer). The density of tomato ketchup at temperatures (5 and 30 °C) are shown in Table (5.1) GSF Egypt tomato ketchup had the highest density (1160.67 kg/m^3), while the Werder tomato ketchup showed the lowest value (1113.28 kg/m^3). These results were in agreement with those obtained by **Ramas and Ibarz (1998)** who found that density decreased with an increase in temperature and increased with an increase in soluble solids concentration. The density of Lidl ketchup were (1118.64 and 1109.64 kg/m^3) at temperature (5 and 10 °C), respectively. During the manufacture of same commercial products, Juice or ketchup is concentrated. It is necessary to know the specific heat changes due to different factors, as a function of moisture content, since, for the purpose of many engineering calculations, the variations due to temperature are small and an average value of specific heat is used for limited temperature ranges (**Lewis 1987**). The specific heat values varied from (2.93 to 3.19 kJ/kg K). These results agreed with the results obtained by **Alvarado (1991)** who found that the specific heat for tomato (3.94, 3.48, 3.18 and 2.93 kJ/kg.K) at moisture content % (94.5, 81.6, 74.8 and 64.1), respectively. The specific heat capacity is required in cooling, freezing and heat processing, and for the calculation of energy demand. Specific heat is used in the estimation of Prandtl group, which is important in process calculation and energy application.

5.1.2.Effect of storage at different temperatures and different times on some physical and chemical properties of tomato ketchups:

A good correlation between the chemical and rheological properties was found. Physico-chemical parameters, i.e., total solids, pectin content, percent of sedimentable pulp had a high effect on rheological properties. There for some chemical and physical properties of the 8 different blends of tomato ketchups are

Table(5.2) Change in chemical composition of tomato ketchups during storage for 2, 4 and 6 months at different storage temperatures

Products	ST* °C	Storage time											
		2 months				4 months				6 months			
		Total solids %	Titratable acidity %	pH value	Total pectic substances %	Total solids %	Titratable acidity %	pH value	Total pectic substances %	Total solids %	Titratable acidity %	pH value	Total pectic substances %
Lidl	5	28.23±0.02	1.411±0.002	3.64±0.00	6.6100	27.88±0.18	1.417±0.004	3.60±0.00	6.6022	27.39±0.39	1.422±0.004	3.46±0.02	6.5322
	20	28.17±0.04	1.414±0.004	3.60±0.01	6.6083	27.53±0.2	1.422±0.006	3.54±0.00	6.5707	27.11±0.18	1.434±0.006	3.38±0.01	6.5149
	30	28.14±0.04	1.419±0.001	3.57±0.00	6.5962	27.21±0.43	1.434±0.000	3.52±0.00	6.5500	26.83±0.15	1.439±0.000	3.35±0.01	6.4891
Kraft	5	24.32±0.13	1.280±0.003	3.73±0.01	5.9238	24.16±0.44	1.289±0.002	3.61±0.01	5.9210	24.08±0.49	1.295±0.002	3.52±0.02	5.9082
	20	24.17±0.16	1.285±0.002	3.69±0.00	5.9180	24.02±0.16	1.296±0.004	3.59±0.00	5.9015	23.83±0.42	1.307±0.004	3.50±0.01	5.8803
	30	24.04±0.52	1.293±0.002	3.67±0.01	5.9122	23.85±0.32	1.312±0.008	3.58±0.00	5.9002	23.72±0.36	1.316±0.008	3.48±0.02	5.8121
Werder	5	24.22±0.11	0.835±0.001	3.83±0.01	5.8239	24.11±0.11	0.845±0.012	3.76±0.03	5.8176	24.01±0.05	0.854±0.012	3.64±0.0	5.8044
	20	24.20±0.04	0.844±0.004	3.82±0.02	5.8131	23.89±0.12	0.853±0.009	3.72±0.02	5.8130	23.23±0.02	0.866±0.009	3.63±0.0	5.7117
	30	24.16±0.12	0.859±0.008	3.81±0.01	5.8022	23.77±0.32	0.885±0.007	3.71±0.03	5.8004	23.21±0.04	0.887±0.007	3.61±0.0	5.6378
Heinz	5	32.27±0.15	1.649±0.007	3.39±0.01	7.9321	32.03±0.27	1.653±0.000	3.35±0.00	7.9188	31.94±0.03	1.655±0.000	3.21±0.01	7.8825
	20	32.09±0.26	1.658±0.011	3.35±0.04	7.9281	31.96±0.04	1.661±0.001	3.29±0.00	7.9116	31.46±0.01	1.667±0.001	3.20±0.01	7.8206
	30	32.02±0.27	1.671±0.009	3.34±0.05	7.9155	31.84±0.32	1.687±0.006	3.27±0.00	7.9026	31.24±0.33	1.689±0.006	3.18±0.0	7.7920
Reichelt	5	26.19±0.02	1.623±0.002	3.49±0.03	5.5253	25.98±0.65	1.629±0.004	3.33±0.00	5.5118	25.82±0.01	1.633±0.004	3.27±0.0	5.4297
	20	26.03±0.22	1.643±0.012	3.47±0.03	5.5044	25.72±0.41	1.653±0.002	3.32±0.00	5.5003	25.44±0.13	1.655±0.002	3.25±0.0	5.3562
	30	25.89±0.02	1.644±0.014	3.45±0.01	5.4931	25.47±0.66	1.663±0.000	3.3±0.00	5.4765	25.20±0.02	1.667±0.000	3.23±0.0	5.2213
Americana Egypt	5	33.33±0.12	1.547±0.021	3.43±0.0	6.4837	33.10±0.12	1.549±0.001	3.34±0.01	6.4711	32.89±0.17	1.553±0.001	3.24±0.0	6.4312
	20	33.09±0.12	1.555±0.009	3.42±0.0	6.4801	32.79±0.12	1.559±0.009	3.27±0.01	6.4620	32.54±0.38	1.560±0.009	3.22±0.01	6.4109
	30	33.05±0.30	1.572±0.011	3.41±0.01	6.4793	32.71±0.09	1.577±0.003	3.25±0.01	6.4404	32.21±0.03	1.579±0.003	3.21±0.0	6.3836
Heinz Egypt	5	31.22±0.12	1.614±0.007	3.72±0.00	6.0020	30.96±0.13	1.622±0.007	3.69±0.01	5.9877	30.81±0.07	1.628±0.007	3.45±0.01	5.9043
	20	31.12±0.65	1.619±0.001	3.69±0.00	5.9982	30.79±0.66	1.631±0.003	3.67±0.00	5.9609	30.39±0.36	1.639±0.003	3.41±0.0	5.8861
	30	31.04±0.03	1.632±0.005	3.66±0.00	5.9912	30.58±0.12	1.637±0.001	3.65±0.00	5.9553	30.36±0.24	1.644±0.001	3.37±0.01	5.8189
G S F Egypt	5	32.42±0.27	1.567±0.005	3.82±0.01	6.8001	32.29±0.47	1.574±0.007	3.76±0.00	6.7721	32.05±0.02	1.578±0.007	3.48±0.01	6.7321
	20	32.28±0.18	1.572±0.007	3.77±0.02	6.7937	32.06±0.35	1.583±0.012	3.74±0.01	6.7433	31.87±0.29	1.594±0.012	3.42±0.01	6.6773
	30	32.27±0.03	1.578±0.005	3.69±0.02	6.7912	32.01±0.55	1.597±0.009	3.70±0.00	6.7359	31.66±0.45	1.612±0.009	3.37±0.0	6.5492

ST * *Storage Temperature*

recorded in Table 5.2. The values of all parameters mentioned in that table are resembling the mean value of three replicates ± SE. These parameters were evaluated at 2, 4 and 6 months during the rest period of shelf storage. The values of these parameters for Lidl tomato ketchup were ranged (26.83 to 28.23), (1.41 to1.44), (3.35 to 3.64) and (6.48 to 6.61) for total solids, titratable acidity, pH value and total pectic substances, respectively. The effect of storage on chemical and physical properties of the 8 different tomato ketchups was determined and data were statistically analysed and recorded in Table 5.2. The results in Table 5.2 showed the 8 types of ketchup stored at the three temperature studied as compared with the controls in Table (5.1), it is immediately apparent that the differences between the controls and the stored samples. The main differences between the controls and the stored samples were: Total solids, pH and total pectic substances values were higher in the controls, also decreased with storage temperature increased (5, 20 and 30 °C). Where titratable acidity was lower in the controls, titratable acidity increased in stored samples with increasing storage temperature. **Porretta and Birzi (1995)** reported similar observations on storage tomato ketchups. Also the results were in agreement with **Landy *et al.* (2002).**

5.1.3. 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 5.3 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:

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. On the other hand the results were in agreement with **Porretta, (1993) and Jimenez, *et al.*, (1989 $_{a,b}$)**.

Equ.-Nr.	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

Table (5.3) 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*

The importance of determining the density is that it contributes with viscosity and their values are used in calculation of the Reynolds number as follows:

$$Re = d.v.\rho / \eta \qquad (5.10)$$

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.

$$Pr = \upsilon/\alpha \qquad (5.11)$$

Where υ = Kinematic Viscosity ($m^2\ s^{-1}$) $\alpha = Cp/K$

5.1.4. Physical and chemical properties of tomato fruits:

Data in Table (5.4) show some chemical and physical properties of the Mature-green tomato and Ripe tomato. From the tabulated data it is clear that the moisture content in the Mature-green tomato and Ripe tomato was 93.04 and 92.24 %, respectively. The titratable acidity and pH values are considered as important factors correlated to the quality and flavour of tomato fruits were (0.49 and 0.63 %) and (4.37 and 4.14), respectively, agreement with **Leoni *et al.* (1998)**. Total carbohydrates are considered as one of the most important quality parameters for tomato fruits and its contributing influence of palatability, quality, processability, texture and viscosity behavior. It was estimated as total sugars, reducing sugars, non-reducing sugars and pectic substances including their fractions. The values of these data for Mature-green tomato and Ripe tomato presented in Table 5.4 showed the levels of these constituents, (2.98 and 1.39) and (3.52 and 2.27) for the total sugars and total pectic substance, respectively. Since carotene contents and lycopene are playing a major contributory role of pigments formation on ripening stage of fruits, subsequently the color of extracted pulp, in addition to its nutritional importance, the carotene content and lycopene of the tomato fruits, were analzed and the data were (1.02 and 3.14) and (2.42 and17.65), respectively. The results were in agreement with **El-Mansy *et al.* (2000 a)** and **Sio *et al.* (1995).**

Table (5.4) Physical and chemical properties of tomato fruits

Components	Mature-green tomato	Ripe tomato
Moisture %	93.04±0.14	92.24±0.08
Total solids %	6.96±0.14	7.76±0.08
Ash %	0.36±0.01	0.53±0.04
Titratable acidity %	0.49±0.01	0.63±0.04
pH value	4.37±0.02	4.14±0.01
Total sugars %	2.98±0.08	3.52±0.06
Reducing sugars %	2.37±0.12	3.16±0.08
Non-reducing sugars %	0.61	0.36
Total pectic substances %	1.39	2.27
Water soluble pectin %	0.49±0.01	0.73±0.04
Ammonium oxalate soluble pectin %	0.23±0.03	1.13±0.06
Acid soluble pectin %	0.67±0.03	0.41±0.02
Color index (O.D. at 420 nm)	0.62±0.01	1.45±0.07
Lycopene mg/100 g	2.42±0.09	17.65±0.16
Carotenoids (mg/l)	1.02±0.00	3.14±0.04

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

5.2. Sensory evaluation of some tomato ketchups:

As in all foods, the organoleptic tests are generally the final guide of the quality from the consumer's point of view. Thus, it was beneficial to make a Comparison between tomatoes ketchup. The texture, color, taste, odor and overall acceptability were that no significant difference for tomato ketchup in consistency color, odor, taste and overall acceptability. On the other hand, the scores showed significant differences between ketchup Heinz Egypt and the other products. The highest scores on consistency for ketchup GSF Egypt (20.92) and lowest scores on consistency for ketchup Heinz Egypt (15.38). The color of ketchup GSF Egypt and ketchup Americana had the higher scores than other tomato ketchup products. The overall acceptability for tomato ketchup Heinz and Heinz Egypt had smaller scores than other ketchup products, (70.44 and 71.00), respectively, (Table 5.5 and Fig., 5.1).

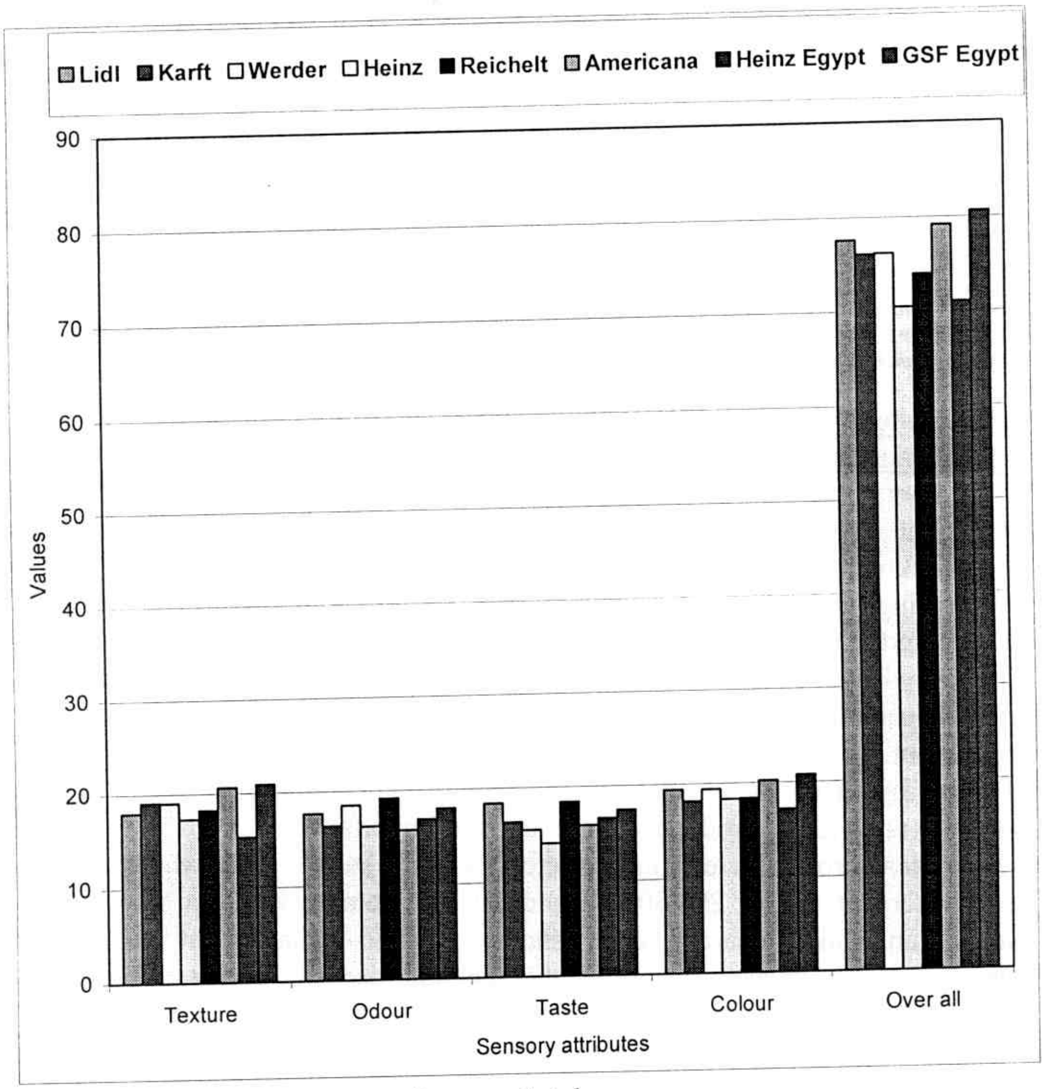


Fig. (5.1) Sensory evaluation of tomato ketchups

Table (5.5) Sensory properties of tomato ketchup

Products	Sensory attributes				
	Consistency (Texture) (25)	Color (25)	Taste (25)	Odor (25)	Overall acceptability (100)
Lidl	18.00^{a}±1.05	19.39^{a} ±0.96	18.39^{b} ±0.88	17.72^{a} ±0.99	77.61^{a} ±3.18
Kraft	19.11^{a} ±0.73	18.17^{a} ±1.39	16.39^{ab} ±1.14	16.39^{a} ±0.91	76.06^{a} ±2.88
Werder	19.06^{a} ±0.99	19.39^{a} ±1.18	15.56^{a} ±1.33	18.50^{ab}±1.13	76.16^{a} ±3.42
Heinz	17.39^{a} ±0.99	18.33^{a} ±1.04	14.11^{a} ±0.74	16.28^{a} ±1.19	70.44^{a} ±2.00
Reichelt	18.28^{a} ±1.47	18.39^{a} ±1.30	18.39^{b} ±1.16	19.17^{b}±1.20	73.89^{a} ±2.80
L.S.D at $p \leq 0.05$	2.9734	3.2746	2.9653	3.0186	8.0273
Americana Egypt	20.62^{b}±0.74	20.23^{b} ±0.53	15.92^{a} ±1.36	15.85^{a} ±1.06	79.15^{b} ±2.28
Heinz Egypt	15.38^{a} ±1.16	17.23^{a} ±1.06	16.62^{a} ±1.23	16.92^{a} ±1.09	71.00^{a} ±3.07
G S F Egypt	20.92^{b}±0.59	20.77^{b} ±0.68	17.46^{a} ±1.01	18.00^{a} ±0.78	80.62^{b} ±2.29
L.S.D at $p \leq 0.05$	2.4076	2.1929	3.3491	2.7379	7.1463

***Values represent of 20 panellists (Mean ±S.E.)**

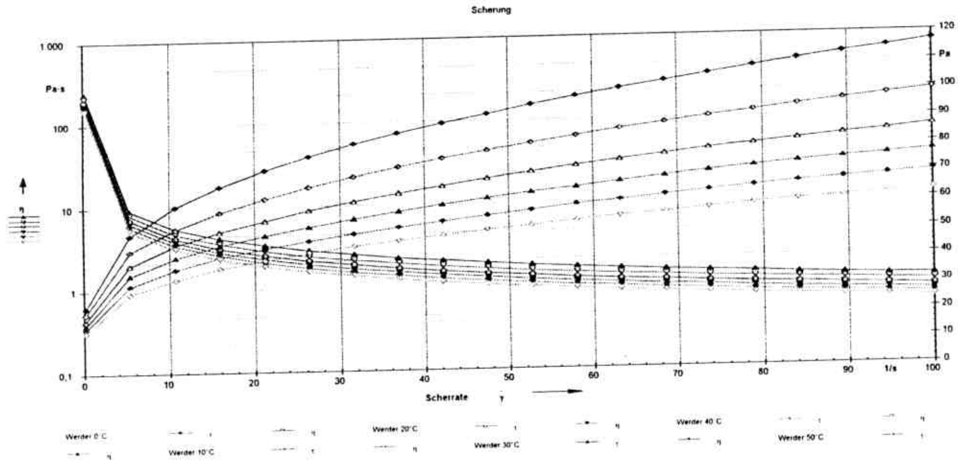
** a, b: There is no significant difference ($p \geq 0.05$) between any two means have the same superscripts, within the same acceptaptability attribute.*

5.3. Rheological properties of some commercial tomato ketchups:

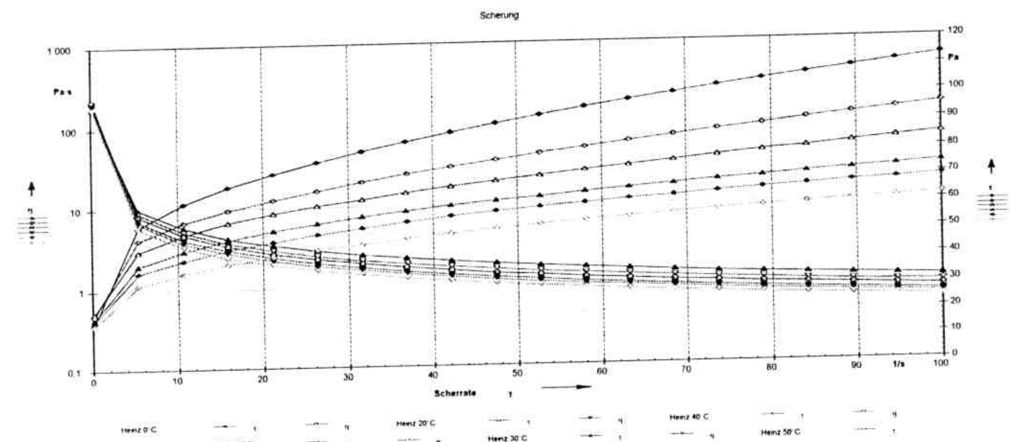
5.3.1.Shear rate examination:

Tomato ketchup is a heterogeneous spiced product made from either cold or hot extracted tomato fruits, tomato concentrates as the base or directly from tomato puree. Viscosity behavior of ketchup is an important attribute from the engineering and consumer view points. The most important single factor determing the quality of commercially processed tomato ketchup is its viscosity. The knowledge of the flow behavior of tomato ketchup is useful for quality control, calculating energy usage, process control and selection of the proper equipment. The type of evaporator, direction of feed and heat transfer rate are all affected by viscosity of the tomato ketchup. Therefore, knowledge of flow behavior at different products of ketchup is of importance.

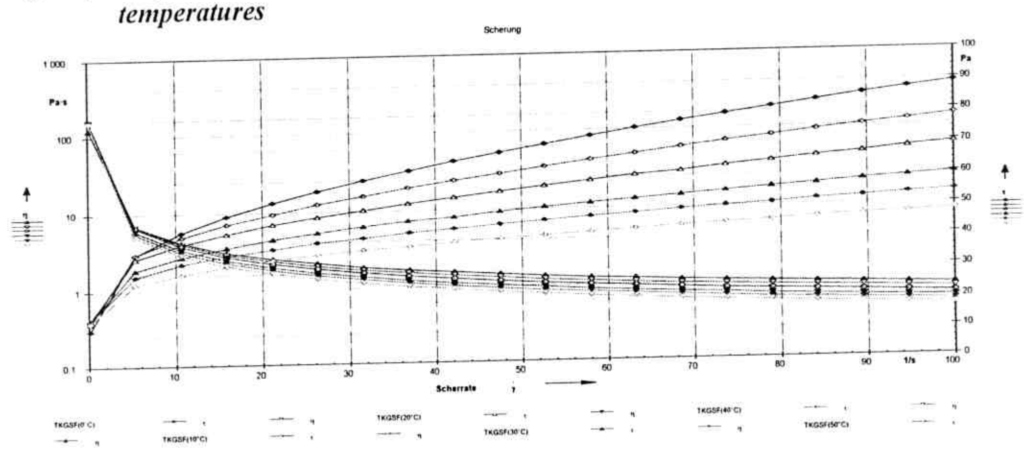
Rheological properties of tomato ketchups were studied at a whole range of temperature at 0, 10, 20, 30, 40 and 50 °C. Tomato ketchup showed non-Newtonian fluids characters. It showed plastic behavior at all assayed temperatures. In "plastic materials" the apparent viscosity decreased as the rate of shear at which the material is tested increased. This plastic behavior is the result of a complex interaction among the pulp, soluble pectin, organic acids and soluble solids **(Rao, 1987)**. The flow and viscosity curve for three ketchups samples at all investigated temperatures were shown in (Figs. 5.2-4). It can be seen that the viscosity curve exhibited shear thinning (Structure viscous) behavior: the viscosity η fell with increasing shear rate. All ketchups samples show strong shear-thinning behavior in the shear rates range $0.1 \leq \dot{\gamma} \leq 100\ s^{-1}$.



(Fig. 5.2) The flow and viscosity curves for the Werder ketchup at all investigated temperatures



(Fig. 5.3) The flow and viscosity curves for the Heinz ketchup at all investigated temperatures



(Fig. 5.4) The flow and viscosity curves for the GSFEgypt ketchup at all investigated temperatures

5.3.1.1 Use of Herschel-Bulkley (HB) model:

The steady flow curves obtained were well described by the HB model. The experimental values of shear stress τ in Pa and shear rate $\dot{\gamma}$ in s^{-1} have been fitted by equation (4.1). τ_0, K, n were calculated, using PHYSICA software US200, and tabulated in Table 5.6.

5.3.1.2 Yield point τ_0:

The yield point is related to the existence of a reticulated structure, which is generally due to the interaction between colloidal particles or the formation of links between the long chain molecules (**Alonso *et al.*,1995**). Yield point τ_0 value was higher for Reichelt, Heinz Egypt, and lower for Heinz, Americana, GSF brands. The highest τ_0 value for the Reichelt and Heinz Egypt ketchups indicated that the forces of the interparticular link were greater than those of the other samples. Some authors consider that the τ_0 value in products of a similar composition is related to the factors which influence gel formation, such as pH, sugar and pectin content (**Alonso *et al.*,1995**). The τ_0 values at temperature 20 °C were 12.39, 11.91, 13.23, 10.74, 14.76, 6.41, 20.69 and 6.81 Pa for all tomato ketchups under studies, respectively. The "τ_0" decreased when the temperature increased for the different tomato ketchups brands under investigation. These data were in agreement with those previously reported by other investigators, **Chaffai (1991) and Young *et al.* (1997)**.

5.3.1.3 Consistency index K :

Consistency index (K) Value was higher for Heinz (30.23 $Pa.s^n$) and lower for Reichelt (13.15 $Pa.s^n$) at 0 °C. These data were in agreement with those previously reported by other investigators**, Canovas and Peleg (1983) and Young *et al.* (1997)**. The reason for such differences in the flow behavior constants between tomato ketchups brands might be referred to the variations in their content of total solids, starch content and pectic substances and particles. Chemical analysis of tomato ketchups brands (Table 5.1) indicated that Heinz tomato ketchup had the highest total pectic substances being 7.93 % and total solids 32.49 %. These results were in agreement with those obtained by **Sharoba (1999)** who reported that the higher "K" values could be referred to the presence of more suspended total pectic substances in the tomato products. On the other hand, the (K) consistency index ($Pa.s^n$) increased with increasing the total solids, and decreased with increasing temperature.

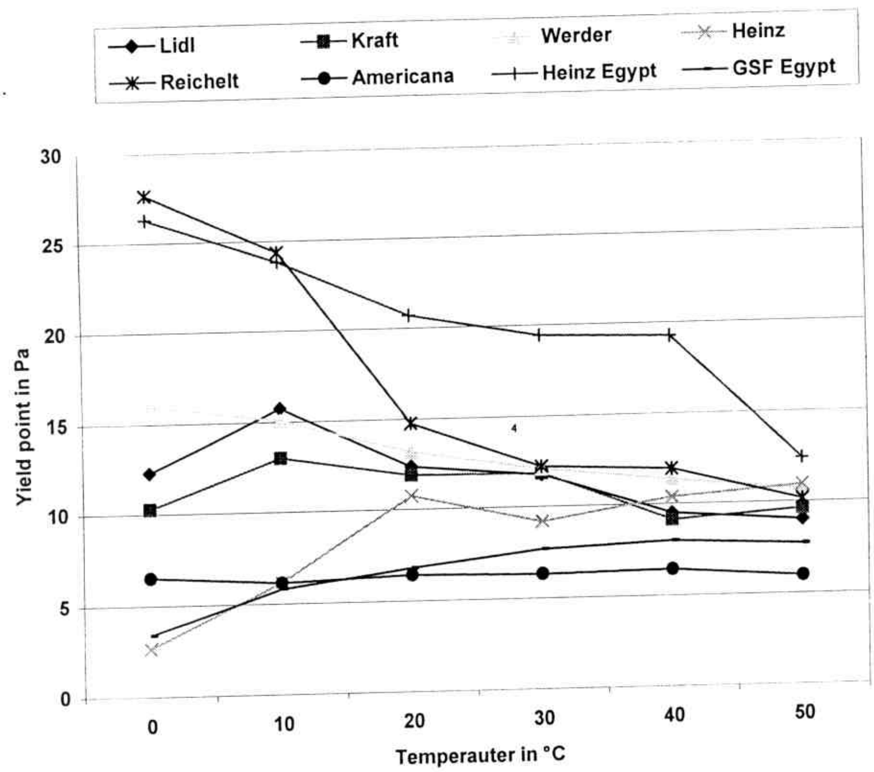
5.3.1.4 Flow behavior index(n):

The flow index (n) values for the tomato ketchup given in Table5.6 were less than one indicating that the rheological behavior is pseudoplastic. The n values ranged between 0.25 and 0.42. These results could be confirmed with the data obtained by **Young *et al.* (1997)**, they indicated that the (n) value 0.36 for tomato ketchup at 25 °C and **Canovas and Peleg (1983),** who indicated that the (n) values obtained from two tomato ketchups (Heinz and Stop& Shop) ranged between 0.38 and 0.40.

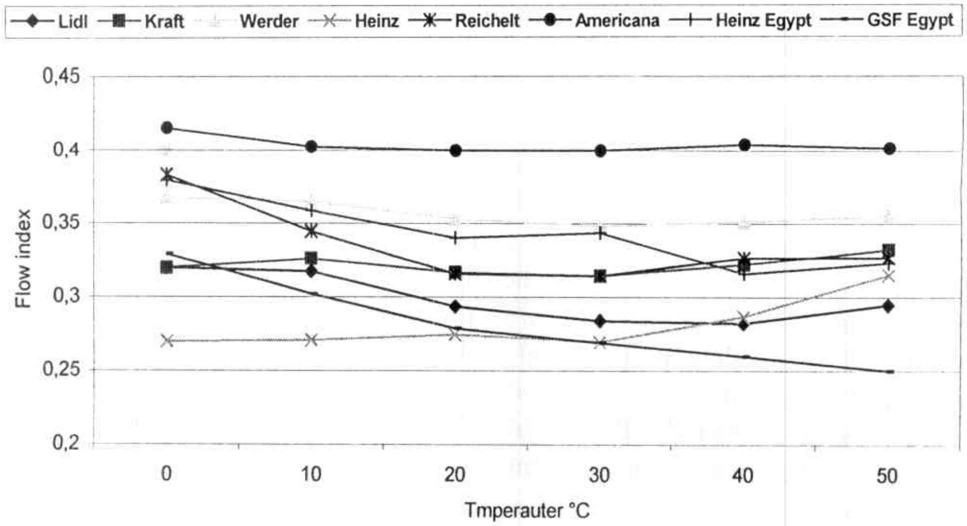
5.3.1.5 Temperature dependence of tomato ketchup on rheological parameters:

It is observed from these results that, K and n decreased as temperature rose. At a given temperature, K increased with increase in total solids. These results could be confirmed with the data obtained by **Ibarz *et al.* (1996a)** who reported that temperature was found to have a large effect on the consistency index but with a little effect on the flow behavior index. The rheological parameters are very important values; from the engineering stand point that they are required to calculate an important dimension less value, which is known as, generalized Reynold's number. Solving the problems of fluid flows and pumping need essentially the Reynold's number **(Toledo, 1980)**. Besides calculation of heat transfer coefficient; for non-Newtonian fluids depends upon the consistency of the fluid as indicated by **Charm (1980).**

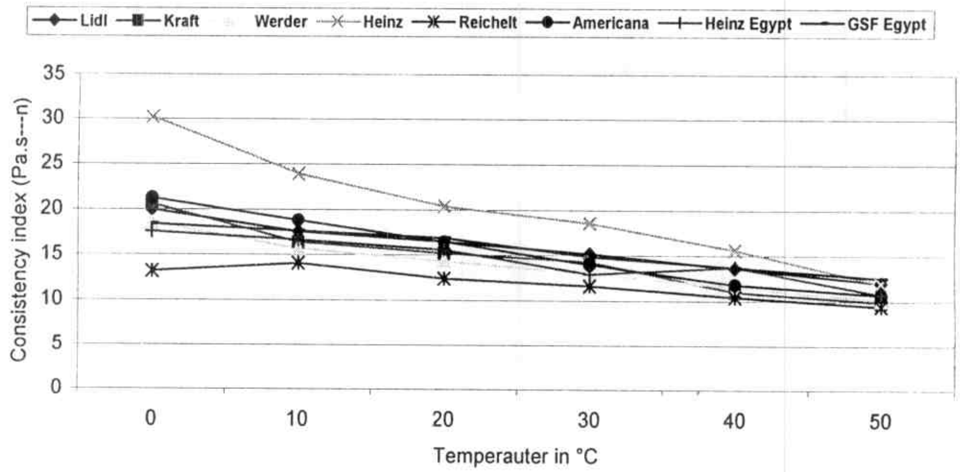
The coefficient of correlation r for HB model ranged from 0.994 to 0.999 for all tomato ketchups samples under studies. The relationship between HB model parameters and temperature are shown in (Figs. 5.5-7).



(Fig. 5.5) Relationship between Herschel-Bulkley model parameters(yield point) and temperature it showed depending of the particle size.



(Fig. 5.6) Relationship between Herschel-Bulkley model (flow index) parameters and temperatures

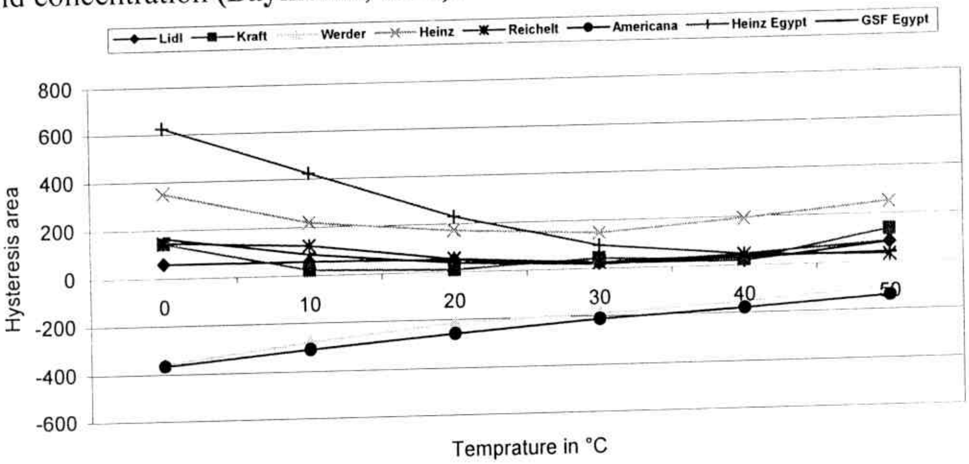


(Fig. 5.7) Relationship between Herschel-Bulkley model parameters and temperatures

5.3.1.6 Thixotropic behavior(A_{TH}):

The characterization of time-dependent flow properties of ketchup is important for food processing and handling, process design and control, product development, structure and flow relationships, and physical parameters and sensory evaluation correlation. Thixotropy values are tabulated also in Table 5.6, and illustrated in (Fig. 5.8). The data showed that tomato ketchups (Lidl, Kraft, Reichelt, Heinz, Heinz Egypt and GSF Egypt) exhibits thixotropic properties but tomato ketchups (Werder and Americana Egypt) exhibits rheopectic could be referred to high content (%) of starch. Also in thixotropic behavior showed the biggest size of particles had small inner friction.

Thixtropy is generally defined as the continuous decrease of apparent viscosity with time under constant shear rate and the subsequent recovery of viscosity when the flow is discontinued. When the temperature is increased, the intermolecular distances increase and therefore the viscosity will decrease for these main reasons. The viscosity is a function of temperature and the dissolved solid concentration **(Bayindirli, 1992).**



(Fig. 5.8) Relationship between thixtropy values for tomato ketchups samples and temperatures. Werder and Americana Egypt exhibits rheopectic

5.3.1.7 Casson model:

The Casson model (CA) (eqn. 4.2) has been used to describe the flow behavior of tomato ketchups in all cases of our examinations. The applicability of the CA model for all tomato ketchups at temperature (0 – 50 °C) was examined by regression analysis of CA parameters. The ranges of r values for tomato ketchups ranged between 0.91 to 0.99. The correlation coefficients indicated reasonably good applicability of the model. The use of the CA model was necessary because the model of HB by storage examination showed that negative yield point was found. The values of rheological constants for tomato ketchups, using the CA model was presented in Table (5.6).

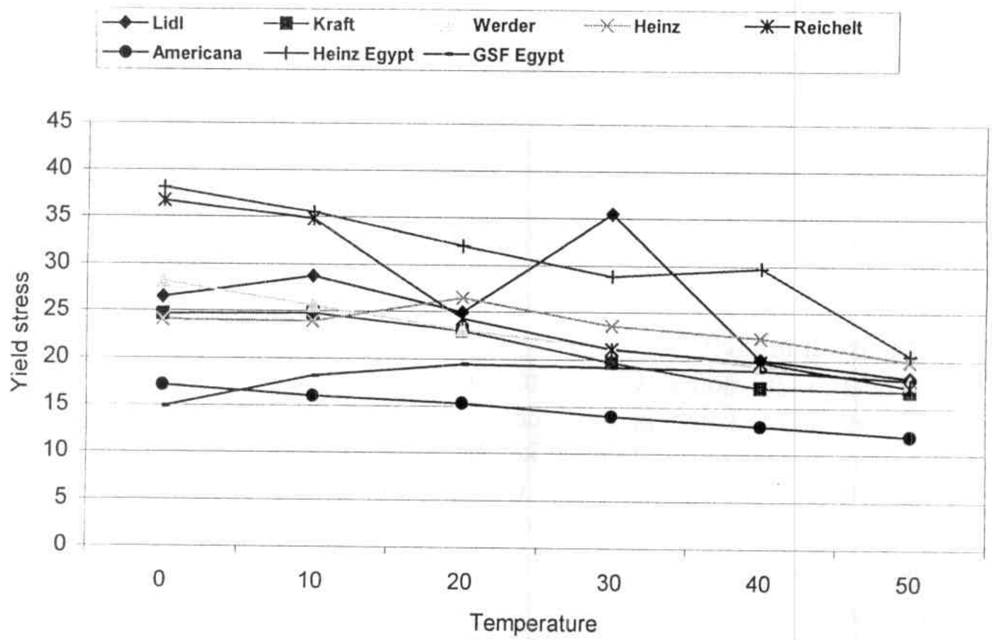
5.3.1.8 Casson yield point (τ_{0CA}):

The yield point values for CA model were higher than those obtained by HB model for all tomato ketchups. Yield point (τ_{0CA}) value was higher for Reichelt, Lidl, Heinz Egypt, and lower for Americana, GSF brands. The τ_{0C} values at temperature 20 °C were 24.96, 22.97, 23.07, 26.53, 24.25, 15.34, 32 and 19.46 Pa for all tomato ketchups under studies, respectively. The "τ_{0CA}" was much higher than that obtained using HB model for the different tomato ketchups brands under investigation. On the other hand the correlation coefficient for Casson model was lower than that obtained using HB model for the different tomato ketchups brands under investigation. These data were in agreement with those obtained by **Correia and Mittal (1999)**.

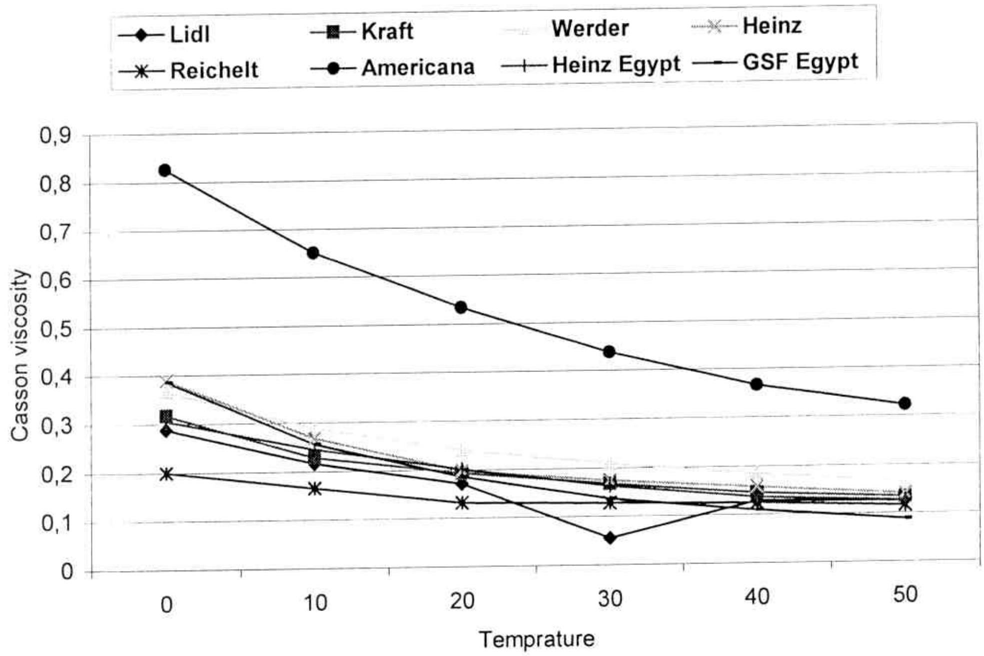
5.3.1.9 Casson dynamic viscosity:

Casson dynamic viscosity decreased as temperature rose for the different tomato ketchups brands under investigation. The Casson viscosity at a given temperature, were (0.37, 0.29, 0.24, 0.21, 0.19, 0.17 Pa.s) and (0.20, 0.17, 0.131, 0.128, 0.125, 0.116 Pa.s) for Werder and Reichelt tomato ketchups, respectively. The results were in agreement with those obtained by **Correia and Mittal (1999), Chaffai (1991) and Canovas and Peleg (1983),** they found that the Casson dynamic viscosity ranged between 0.11 to 0.70 Pa.s.

The relationship between CA model parameters and temperature are illustrated in (Figs. 5.9-10).



(Fig. 5.9) Relationship between Casson model parameters (yield stress) and temperature for tomato ketchups



(Fig. 5.10) Relationship between Casson model parameters (Casson viscosity) and temperature for tomato ketchups

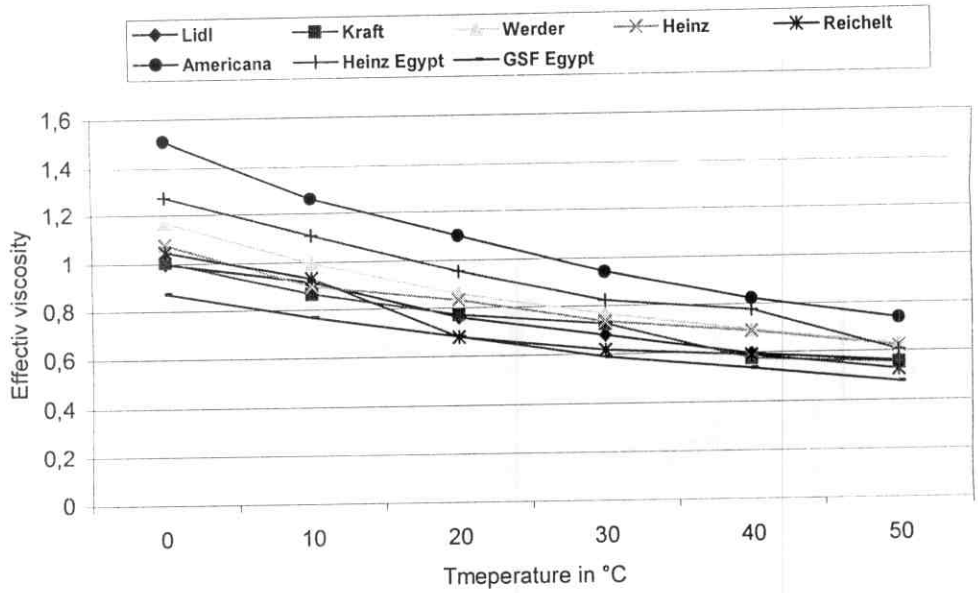
5.3.2 Effective viscosity (η_{eff}):

Effective viscosity was calculated for HB model and CA model by using equations (4.4) and (4.5), respectively, as mentioned by **Senge (2001).** The results were presented in Table 5.6 and illustrated in Figs., 5.11-12

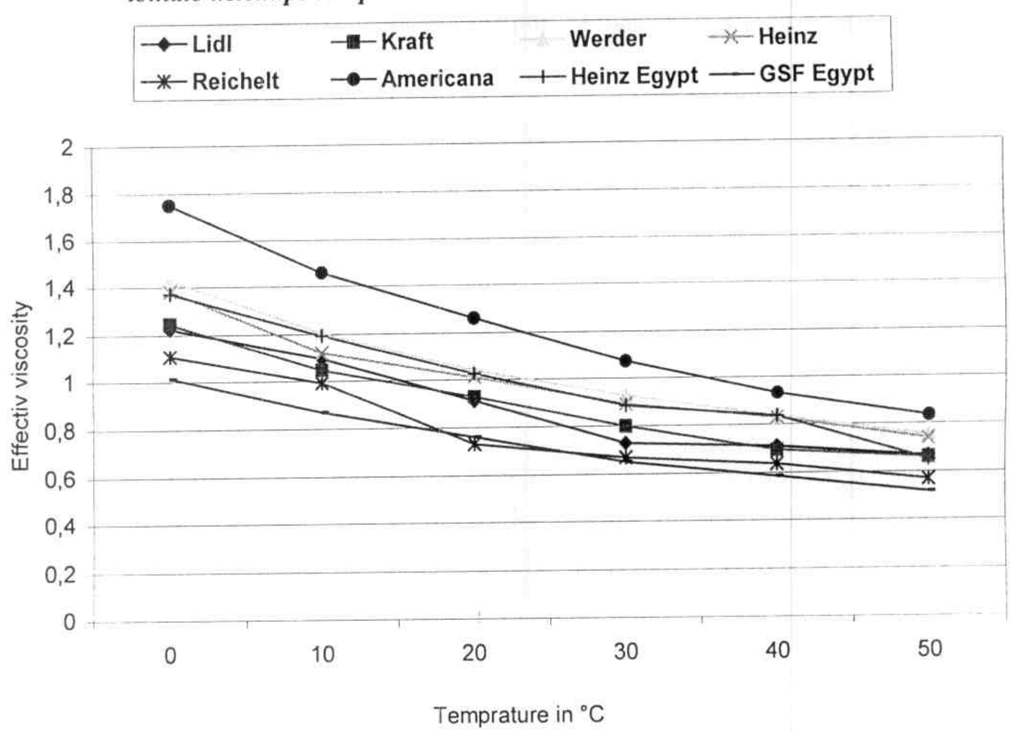
$$\eta_{eff} = (\tau_{0HB} / \dot{\gamma}) + K \cdot \dot{\gamma}^{\,n-1} \quad (4.4)$$

$$\eta_{eff} = (\tau_{0CA} / \dot{\gamma}) + \eta_{CA} + 2\,((\tau_{0CA})^{0.5} \cdot (\eta_{CA} / \dot{\gamma})^{0.5}) \quad (4.5)$$

The relationship between ($\eta_{eff\ HB}$ and $\eta_{eff\ CA}$) and temperature of all tomato ketchups brands under investigation was examined. Higher significantly correlation was found between ($\eta_{eff\ HB}$ and $\eta_{eff\ CA}$) and temperature. The $\eta_{eff\ HB}$ and $\eta_{eff\ CA}$ decreased with increasing the temperature. The $\eta_{eff\ HB}$ for Lidl ketchup was (0.996, 0.915, 0.76, 677, 0.593 and 0.557) at assayed temperature, respectively. Where the $\eta_{eff\ CA}$ values for Lidl ketchup were (1.224, 1.096, 0.911, 0.728, 0.71and 0.667) at assayed temperature, respectively. The $\eta_{eff\ CA}$ values were higher than $\eta_{eff\ HB}$ values for all tomato ketchups brands.



(Fig., 5.11) Relationship between HB effective viscosity ($\eta_{eff\,HB}$) values and temperature for tomato ketchups samples.



(Fig., 5.12) Relationship between Casson effective viscosity ($\eta_{eff\,CA}$) values and temperature for tomato ketchups samples. These data are very important for the calculation of process equipments. The use of one of the rheological modeles estimated the level of effective viscosity.

Table(5.6) Herschel-Bulkley and Casson parameters of some selected commercial tomato ketchups at zero time

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	12.3068	20.0285	0.3197	0.9985	1.0504	0.9961	26.5333	0.2887	0.9586	5.5607	1.2236	58.1471
	10	15. 7275	17.5870	0.3172	0.9991	0.6950	0.9151	28.7459	0.2155	0.9642	4.4665	1.0958	57.2791
	20	12.3860	16.4536	0.2936	0.9994	0.4677	0.7599	24.9576	0.1708	0.9569	3.9701	0.9105	50.7233
	30	11.7691	15.1366	0.2841	0.9997	0.2820	0.6777	35.4484	0.0549	0.9997	0.0553	0.7278	21.8698
	40	9.4902	13.5721	0.2825	0.9997	0.2508	0.5934	20.0481	0.1287	0.9521	3.2089	0.7096	20.3319
	50	9.0160	12.0232	0.2944	0.9998	0.2050	0.5566	18.2108	0.1256	0.9548	2.9749	0.6668	84.2759
Kraft	0	10.2800	20.6487	0.3195	0.9991	0.9003	1.0021	24.6636	0.3174	0.9527	6.1084	1.2462	142.9456
	10	13.0214	16.3841	0.3258	0.9992	0.6494	0.8648	24.7686	0.2286	0.9625	4.4832	1.0478	21.7734
	20	11.9059	15.1682	0.3165	0.9997	0.3698	0.7706	22.9701	0.1932	0.9593	4.0627	0.9269	10.6336
	30	11.8486	14.2565	0.3143	0.9997	0.3075	0.7247	19.6671	0.1669	0.9579	3.5513	0.7972	42.5832
	40	9.1167	10.9722	0.3221	0.9998	0.2041	0.5748	17.1063	0.1449	0.9598	3.0243	0.6928	23.3525
	50	9.6065	9.8657	0.3323	0.9997	0.2376	0.5518	16.7458	0.1347	0.9652	2.6940	0.6609	137.5546
Werder	0	15.9199	18.5343	0.3679	0.9999	0.04122	1.1679	28.1360	0.3653	0.9629	6.3667	1.4287	-357.5409
	10	15.0714	15.6712	0.3651	0.9999	0.1738	0.9927	25.6122	0.2887	0.9665	5.0499	1.2037	-278.0301
	20	13.2298	14.2858	0.3531	0.9999	0.2067	0.8586	23.0712	0.2404	0.9649	4.4049	1.0397	-213.8128
	30	12.1083	13.0206	0.3481	0.9999	0.1391	0.7680	21.1963	0.2089	0.9640	3.9469	0.9277	-190.1649
	40	11.3622	11.4883	0.3513	0.9999	0.0876	0.6929	19.3742	0.1851	0.9648	3.5061	0.8343	-152.0508
	50	10.6891	10.1207	0.3556	0.9999	0.0505	0.6274	17.7294	0.1650	0.9661	3.1071	0.7532	-100.8229
Heinz	0	2.6142	30.2300	0.2702	0.9991	0.9485	1.0753	24.0594	0.3886	0.9178	8.6473	1.3835	349.7060
	10	6.1703	23.9665	0.2712	0.9991	0.7446	0.8973	23.9245	0.2683	0.9339	6.2027	1.1213	219.4178
	20	10.7426	20.4536	0.2750	0.9989	0.3698	0.8331	26.5325	0.1980	0.9494	4.7585	1.0092	172.5254
	30	9.1715	18.5896	0.2697	0.9998	0.2739	0.7354	23.5833	0.1735	0.9428	4.4259	0.8908	148.6840
	40	10.3718	15.5825	0.2868	0.9999	0.2041	0.6875	22.3236	0.1576	0.9499	3.8681	0.8266	193.5472
	50	10.9494	11.9643	0.3147	0.9999	0.2376	0.6192	19.8856	0.1414	0.9602	3.1409	0.7389	250.4545

Table(5.6) Continue: Herschel-Bulkley and Casson parameters of some selected commercial tomato ketchups at zero time

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	27.6880	13.1533	0.3831	0.9994	0.6447	1.0447	36.7479	0.1996	0.9844	3.2253	1.1087	146.8294
	10	24.3318	14.0371	0.3447	0.9994	0.5482	0.9299	34.7677	0.1651	0.9780	3.2895	0.9919	123.3966
	20	14.7636	12.3765	0.3156	0.9999	0.1487	0.6771	24.2506	0.1312	0.9657	3.0311	0.7305	54.7101
	30	12.2438	11.6158	0.3141	0.9999	0.1317	0.6159	21.0962	0.1279	0.9602	3.0248	0.6674	25.5546
	40	11.9710	10.4172	0.3266	0.9998	0.2228	0.5885	19.7830	0.1247	0.9615	2.8683	0.6367	46.0923
	50	10.1615	9.4036	0.3268	0.9997	0.2132	0.5252	17.1709	0.1159	0.9600	2.6433	0.5698	32.7503
Americana Egypt	0	6.5122	21.2910	0.4157	0.9996	0.9983	1.5091	17.1629	0.8258	0.9485	11.2348	1.7504	-365.9452
	10	6.1268	18.8290	0.4023	0.9998	0.6427	1.2618	16.0685	0.6504	0.9470	9.3570	1.4576	-307.8464
	20	6.4094	16.4216	0.3998	0.9998	0.4675	1.0991	15.3400	0.5344	0.9503	7.7937	1.2604	-258.4437
	30	6.3150	13.9206	0.3999	0.9999	0.3628	0.9411	14.0247	0.4372	0.9537	6.3864	1.0727	-210.2129
	40	6.4040	11.8069	0.4042	0.9998	0.3292	0.8235	12.9999	0.3659	0.9587	5.2461	0.9321	-179.5318
	50	5.9523	10.6568	0.4018	0.9998	0.3264	0.7374	11.9742	0.3213	0.9596	4.6281	0.8333	-139.0691
Heinz Egypt	0	26.3161	17.5841	0.3794	0.9986	1.26334	1.2720	38.1299	0.3063	0.9806	4.7280	1.3711	625.0226
	10	23.7951	16.6321	0.3587	0.9977	1.3722	1.1055	35.4976	0.2461	0.9789	4.1598	1.1922	422.1681
	20	20.6927	15.5263	0.3402	0.9973	1.2633	0.9507	32.0046	0.2001	0.9760	3.7222	1.0263	228.5369
	30	19.4517	12.8961	0.3437	0.9963	1.2454	0.8224	28.8669	0.1622	0.9787	2.9863	0.8836	96.0905
	40	19.2523	13.6668	0.3157	0.9942	1.4109	0.7773	29.7340	0.1358	0.9754	2.8948	0.8350	46.3696
	50	12.4338	10.7888	0.3232	0.9970	0.8365	0.6023	20.4674	0.1265	0.9724	2.5165	0.6530	85.5568
G S F Egypt	0	3.3556	18.4351	0.3292	0.9990	0.8425	0.8729	14.8807	0.3854	0.9321	6.8829	1.0132	165.8373
	10	5.8053	17.6516	0.3019	0.9984	0.8645	0.7668	18.1530	0.2563	0.9436	5.1326	0.8692	87.0963
	20	6.8057	16.9099	0.2789	0.9984	0.7351	0.6790	19.4596	0.1853	0.9457	4.1879	0.7597	38.0513
	30	7.6497	14.8182	0.2692	0.9991	0.4576	0.5885	19.1805	0.1359	0.9476	3.3804	0.6506	17.0361
	40	7.9699	13.6992	0.2601	0.9994	0.3217	0.5335	18.9045	0.1093	0.9477	2.9408	0.5858	35.8265
	50	7.6914	12.5435	0.2501	0.9995	0.2563	0.4738	17.9229	0.0878	0.9472	2.5352	0.5179	40.3726

5.3.3. Activation energy and the effect of temperature on viscosity of tomato ketchups:

The activation energy of flow has been related to some fundamental thermodynamic properties of the Newtonian fluids. For example ΔEa has been found to be approximately equal to 1/3 or 1/4 the heat of vaporization, depending on the shape and bonding of liquid molecules. Empirical equations have been suggested for the estimation of the activation energy as a function of the viscosity and the temperature of various classes of liquids **VanWazer *et al.*(1963).** Activation energy decreased significantly when suspended particles were present in the product, as in cloudy juices and fruit purees. In pseudoplastic fruit products, the activation energy was directly proportional to the flow behavior index i.e., the more pseudoplastic the product, the less the effect of temperature on its apparent viscosity.

Activation energies of the pseudoplastic products (tomato ketchup) reported on Table (5.7) were calculated at a constant shear rate (100 s^{-1}). Viscosity decreased with increasing temperature. This effect of temperature on the flow behavior of fluid foods can be described by the Arrhenius relationship **(Ibarz *et al*, 1995); Singh and Eipeson (2000); Yoo (2001) and Kaya (2001).**

Table (5.7) Arrhenius-type constants relating the effect of temperature and viscosity at 100 RPM on tomato ketchup

Products	Ea (kJ/mol)	η_∞ (mPa.s)	Coefficient of Correlation (R^2)	Temperature range °C
Lidl	9.336	2.828	0.995	0 - 50
Kraft	7.711	3.558	0.992	0 - 50
Werder	9.055	3.059	0.999	0 - 50
Heinz	7.124	3.79	0.997	0 - 50
Reichelt	10.873	2.24	0.975	0 - 50
Americana Egypt	10.649	2.635	0.999	0 - 50
Heinz Egypt	10.195	2.69	0.985	0 - 50
G S F Egypt	9.162	2.765	0.999	0 - 50

The Arrhenius constants for the temperature range 0-50 °C (η_∞ and E_a), together her with regression coefficients are listed in Table (5.7). For the flow activation energy, the values ranged from (7.12-10.87 kJ/mol) depended on the chemical composition and physical properties (particle size, pectin content, effect of starch and total solid). The activation energy increased with the soluble solids contents increase in i.e. tomato ketchup Americana Egypt total solids (33.35 %) and E_a (10.65 kJ/mol) and Kraft tomato ketchup total solids (24.36 %) and E_a (7.71 kJ/mol). These results were in agreement with those obtained by **Upasana and Bains (1987)** who reported that the activation energy of laboratory ketchups (3.36 kcal / mole) and (4.88 kcal / mole) for commercial ketchup samples. Also these results were trend in accordance with that reported by other authors for different tomato products with similar characteristics **Harpar and El Sahrigi (1965)** who reported that E_a of 3.83 Kcal mole^{-1} K for a tomato juice concentrate of 30 % solids using high shear rates of 500 to 800 s^{-1}. **Rao *et al.* (1981)** reported E_a values of 2.3±0.3 kcal mole^{-1} K for tomato concentrates of 30 to 36 % solids. On the other hand E_a calculations may be useful in estimating the effect of homogenisation where it would be hypothesized that the homogenized concentrate would have a higher E_a than the non homogenized control due to an increase in the number of insoluble particles, decrease in particle size and decrease in viscosity. Arrhenius plots for tomato ketchup samples are shown in Fig. (5.13)

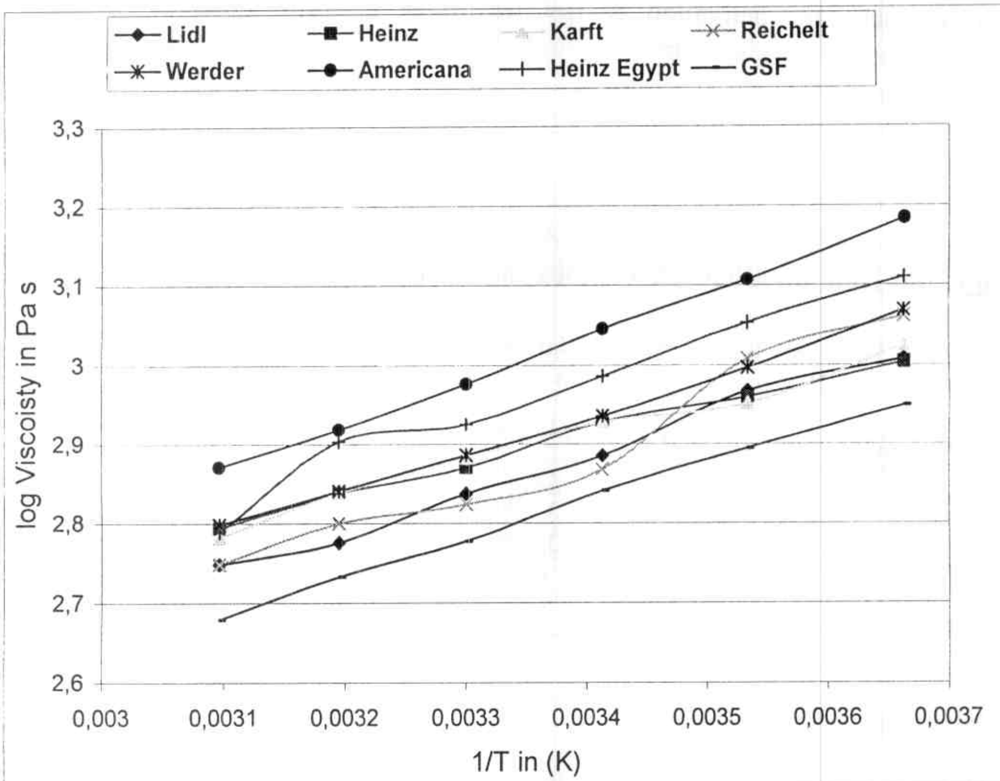


Fig. (5.13) Arrhenius plots for tomato ketchup samples

5.3.4. Oscillation tests:

There are few published articles about Oscillation reological tests for tomato ketchup, juice, puree and paste using US200 Oscillatory rheometer

Amplitude sweeps (AS):

The amplitude sweep should achieve the following three aims:

- Determination of the best limit of the linear viscoelastic range (LVE range). The limit of range is exceeded at the point at which the first of the two curves (G′ or G′′ function) begins to leave the constant plateau value significantly (e.g. showing a decreasing G′ value). The permitted bandwidth can be defined by the user, 10 % of difference are possible.

- Characterization of the material structure: Does the sample show solid character with G′> G′′ or liquid character with G′′ > G′?

All the ketchups samples show G′> G′′ in the LVE range, which means they all have solid character at very low deformation during Oscillation tests.

- Evaluation of the structural strength as the G′ value in the LVE range (sometimes called„rigidity”).

Fig. 5.14 shows the Amplitude sweeps for all tomato ketchups blends at temperature 20 °C. The value of G′ was more than G′′, which showed that the tomato ketchups were more elastic than viscous.

Frequency sweeps (FS):

A frequency test was made to evaluate the viscoelastic behavior of tomato ketchup under measurement condition. The oscillatory tests were carried out with frequency range $0.001 \leq f \leq 100$ Hz and at temperature 0, 10, 20, 30, 40 and 50 °C. Figs. (5.14) and (5.15) show the amplitude and frequency sweeps for tomato ketchups at 20 °C. Plots of log ω vs log G′, log G′′ dynamic rheological data were subjected to linear regression and the magnitudes of intercepts (K_1` and K_2``), slopes (x′ and y′′), and R^2 in the equations (4.6 and 4.7) were summarized in Table (5.8). Confirmed the shear-thinning nature of the tomato ketchup samples and that G′ was higher than G′′ at all values of ω employed.

$$G' = K_1'(\omega)^{x'} \qquad (4.6)$$

$$G'' = K_2''(\omega)^{y''} \qquad (4.7)$$

When storage and loss modulus as well as loss angle are plotted versus angular frequency, ω, the visco-elastic behavior of the sample can be described very well by (**Kunzek *et al.*, 1997**).

From a structural point of view, it is known that for true gels log ω vs log G′ or log G′′ plots have zero slopes **Rao and Cooley (1992) and Yoo and Rao (1996 a,b)**, while for weak gels and highly concentrated solutions such plots have positive slopes and G′ is higher than G′′ over large ranges of ω. In addition, as discussed in detail below, magnitudes of η^* were greater than η for all magnitudes of shear rates and oscillatory frequencies. This means that tomato ketchup did not behave as true gels, but exhibited weak gel properties. These results agreed with the results obtained by **Yoo and Rao (1996a); Mezger (2003)**, they found that the rheological behavior of tomato pastes, concentrates and tomato ketchup is that of weak gels.

Steventon *et al.*(1991) studied the frequency sweeps for the gel foodstuff (yoghurt, for example) and they shows four separate regions:

1. A linear viscoelastic region in which G′ and G′′ are constant and the material is predominantly elastic (G′>> G′′);
2. A non-linear region in which G′′ is fairly constant and G′ starts to decrease, indicating breakdown of the elastic structure;
3. Where G′ and G′′ cross over after the full elastic structure has been broken and the material becomes more viscous; and
4. Where viscous behavior dominates (G′′>>G′).

Table (5.7) Dynamic shear data of some selected tomato ketchups [constants* of (G′, G′′) versus (frequency, rad S^{-1})]

Product	T	G′ Constant (K_1′)	G′ Constant (x′)	G′ R^2	G′′ Constant (K_2′′)	G′′ Constant (y′′)	G′′ R^2	Product	T	G′ Constant (K_1′)	G′ Constant (x′)	G′ R^2	G′′ Constant (K_2′′)	G′′ Constant (y′′)	G′′ R^2
Lidl	0	307.36	0.1691	0.997	67.915	0.3463	0.998	Reichelt	0	476.73	0.1354	0.999	84.4310	0.2496	0.999
	10	299.44	0.1467	0.999	56.772	0.3304	0.999		10	395.98	0.1070	0.998	67.5040	0.2208	0.999
	20	292.52	0.1209	0.999	52.074	0.3146	0.999		20	380.35	0.1032	0.999	58.0750	0.2397	0.998
	30	272.88	0.1183	0.996	41.486	0.3042	0.999		30	339.21	0.1143	0.996	51.0240	0.2257	0.999
	40	267.93	0.1158	0.995	41.222	0.2844	0.998		40	319.34	0.1219	0.994	45.6410	0.2435	0.998
	50	233.4	0.0999	0.995	40.369	0.2586	0.998		50	317.09	0.0906	0.998	46.6270	0.2235	0.997
Kraft	0	259.85	0.1508	0.998	57.622	0.3399	0.995	American Egypt	0	129. 14	0.1818	0.999	25.703	0.3132	0.998
	10	255.35	0.1233	0.997	51.782	0.3280	0.998		10	123.41	0.1554	0.998	22.532	0.3142	0.998
	20	250.82	0.1225	0.999	46.731	0.3081	0.995		20	121.54	0.1454	0.994	19.04	0.3076	0.999
	30	247.17	0.1080	0.997	43.489	0.2880	0.997		30	114.56	0.1150	0.998	18.651	0.3054	0.998
	40	233.55	0.1021	0.996	37.741	0.2695	0.997		40	106.66	0.1154	0.999	16.594	0.306	0.997
	50	230.49	0.1014	0.994	31.326	0.2583	0.999		50	100.14	0.1081	0.996	16.701	0.3001	0.996
Werder	0	208.28	0.1523	0.998	38.974	0.2727	0.998	Heinz Egypt	0	486.48	0.1329	0.999	89.521	0.2995	0.999
	10	195.25	0.1467	0.997	35.749	0.2596	0.998		10	448.73	0.1264	0.999	75.446	0.2857	0.999
	20	184.9	0.1445	0.995	34.526	0.2447	0.997		20	398.21	0.1241	0.998	59.291	0.2779	0.999
	30	180.21	0.1329	0.996	31.78	0.2311	0.996		30	376.41	0.1119	0.997	57.196	0.2685	0.999
	40	177.42	0.1211	0.995	29.48	0.2262	0.998		40	364.83	0.1044	0.999	45.452	0.2559	0.999
	50	171.53	0.1142	0.999	26.80	0.2217	0.997		50	339.67	0.0953	0.998	42.598	0.2385	0.999
Heinz	0	323.52	0.158	0.999	66.122	0.3337	0.999	GSF Egypt	0	381.04	0.1689	0.997	79.666	0.3183	0.999
	10	313.49	0.1401	0.999	54.888	0.3287	0.999		10	345.54	0.1526	0.998	72.905	0.3178	0.999
	20	309.19	0.1156	0.997	49.472	0.3226	0.999		20	328.99	0.1392	0.999	61.716	0.3106	0.999
	30	297.17	0.1063	0.998	47.421	0.3067	0.998		30	312.51	0.139	0.996	52.056	0.3070	0.998
	40	289.82	0.1022	0.995	41.898	0.2934	0.997		40	307.56	0.1158	0.998	47.186	0.3016	0.999
	50	286.39	0.0835	0.998	35.227	0.2895	0.998		50	293.09	0.1129	0.997	46.686	0.2978	0.998

Loss angle δ (phase angle) values:

Another popular material function used to describe viscoelastic behavior is the tangent of the phase shift or phase angle (called tan delta) which is also a function of frequency (**Steffe 1996**):

$$\tan \delta = G''/G' = \eta'/\eta'' \qquad (4.8)$$

This parameter is directly related to the energy lost per cycle divided by the energy stored per cycle. Since $(0 \leq \delta \leq -\pi/2)$, tan δ can very from zero to infinity. The parameters tan δ is a parameters to describe the structural stability of a products. Observations of polymer systems give the following numerical ranges for tan δ: very high for dilute solutions, 0.2 to 0.3 for amorphous polymers, low (near 0.01) for glassy crystalline polymers and gels. Values of tan δ for all tomato ketchups at ω = 1 Hz are listed in Table (5.9) it showed that greater than 0.1, meaning that samples are not true gels. These samples have a structure as weak gel. Tan δ ranged between 0.27 to 0.18, 0.29 to 0.17, 0.24 to 0.19, 0.25 to 0.16, 0.21 to 0.17, 0.3 to 0.2, 0.23 to 0.16 and 0.27 to 0.19 for Lidl, Kraft, Werder, Heinz, Reichelt, Americana, Heinz Egypt and GSF Egypt tomato ketchups, respectively. Significantly correlation was found between (tan δ) and temperature. The tan δ decrease with increase in temperature.

Table(5.9): Results of the frequency sweeps (tan delta) for tomato ketchups samples at different temperatures

T	Lidl	Kraft	Werder	Heinz	Reichelt	American Egypt	Heinz Egypt	GSF Egypt
0	0.273 ±0.015	0.291 ±0.017	0.238 ±0.009	0.245 ±0.014	0.205 ±0.007	0.295 ±0.013	0.227 ±0.012	0.267 ±0.014
10	0.224 ±0.012	0.243 ±0.014	0.243 ±0.014	0.230 ±0.014	0.197 ±0.008	0.272 ±0.011	0.205 ±0.01	0.248 ±0.012
20	0.197 ±0.012	0.219 ±0.016	0.219 ±0.022	0.213 ±0.015	0.188 ±0.01	0.243 ±0.011	0.200 ±0.012	0.226 ±0.014
30	0.200 ±0.014	0.214 ±0.014	0.251 ±0.048	0.190 ±0.014	0.176 ±0.008	0.228 ±0.013	0.179 ±0.01	0.220 ±0.015
40	0.177 ±0.011	0.197 ±0.012	0.199 ±0.009	0.188 ±0.014	0.182 ±0.009	0.21 ±0.011	0.167 ±0.01	0.190 ±0.013
50	0.178 ±0.012	0.167 ±0.011	0.192 ±0.007	0.161 ±0.01	0.171 ±0.009	0.202 ±0.01	0.157 ±0.01	0.189 ±0.013

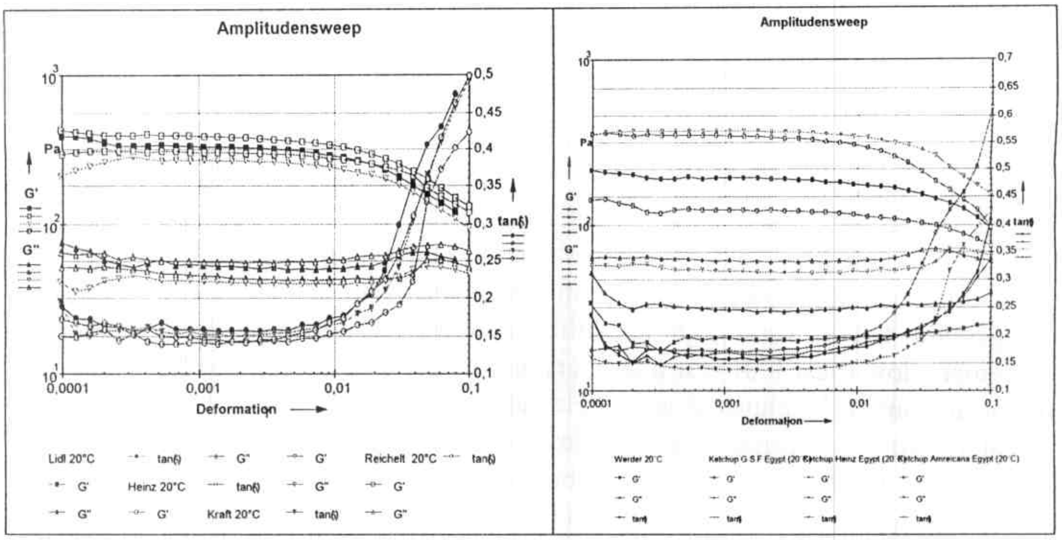


Fig. 5.14 Amplitude sweeps for tomato ketchups at temperature 20 °C. The storage modulus(G′) and loss modulus (G′′) curves are shown as a function of the deformation (γ).

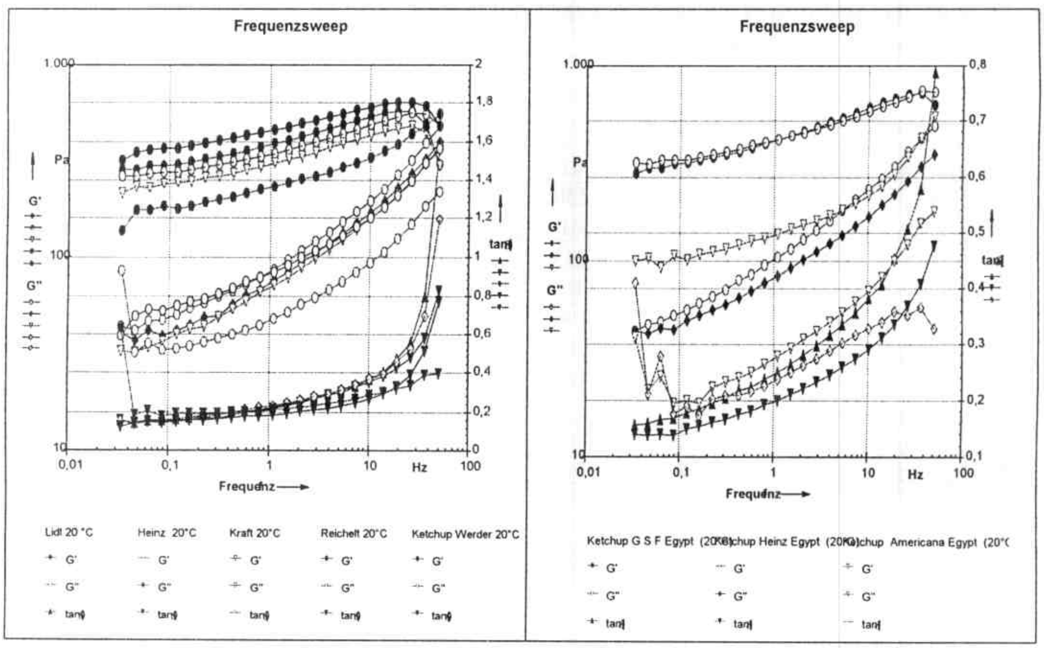


Fig. 5.15 Frequency sweeps: Storage (G′) and loss (G′′) modulus for tomato ketchups are shown as a function of the frequency at temperature 20 °C.

5.3.5. Effect of storage at different temperatures and different times on rheological properties of tomato ketchups:

Viscosity is an important component of the quality of fluid and semi fluid foods. Many foods, such as tomato ketchup, are required to spread and flow easily under a small external force but to hold their shape when not subjected to any such force (**Bourne 2002**).

The nature of the components of tomato ketchup (i.e., starch, sugar, pectin, organic acids, etc.,) plays a significant role in viscosity. From such point of views, the viscosity could be used as a mirror to reflect the changes in tomato ketchups components as a result of storage at different conditions of time and temperature.

Data in Tables (5.10-12) showed the changes in rheological behavior (Herschel-Bulkley and Casson models parameters) of the presented tomato ketchups after two months of storage at 5, 20 and 30 ° C. It was clear that the all tomato ketchups samples affected by storage time and storage temperature. All samples showed a decrease in apparent viscosity as shear rate increased (shear thinning), a characteristic of pseudoplastic behavior. This was in agreement with previous work of (**Howard 1991; Varela *et al.*2003**)

Use of Herschel-Bulkley (HB) model:

Herschel-Bulkley equation is a useful model for fluids exhibiting both a yield point and shear-thinning behavior. The steady flow curves obtained at storage condition were well described by HB Model. All ketchups samples exhibited pseudoplastic characteristics with n less than one. The numerical values of the rheological parameters of the samples showed that there was large difference in the magnitudes of consistency index, but there was little difference in their flow behavior index as an indicator for structure reduction

Yield point (τ_{0HB}):

Yield point is an important property of food dispersions in the coating of solid surfaces and in keeping small solid particles in suspension **Yoo *et al.*, (1995)**. After 2-month storage at 5, 20 and 30 °C there was a significant decrease of yield point for tomato ketchups samples. τ_{0HB} was 6.41 Pa before storage and decreased to 4.33 Pa after storage at 5 °C, to 4.30 Pa after storage at 20 °C and to 4.16 Pa for the Americana ketchup stored at 30 °C. The magnitude of yield point is related to the strength of the coherent network structure as the force per unit area required to breakdown the structure, followed by a rupture of network bond or linkages connecting the flow units. The decrease in yield point may be related to the formation of a softer network of particles. It may be due to the expulsion of liquid from the matrix upon storage, it must act as a lubricant among particles thus reducing particle-particle interactions as well as the resistance to flow. In the same time the yield point values of ketchup were correlated with pectin content (**Upasana and Bains, 1987**) .

Consistency index (K):

The magnitude of K of the tomato ketchup samples increased significantly ($p < 0.05$) and ($p < 0.001$) for 2-month during storage at 5, 20 and 30 °C. It was 16.91 Pa.s^n before storage (at zero time) and it increased to 20.4, 24.85 and 26.26 Pa.s^n at 5, 20 and 30 °C, respectively. By increasing storage temperature the consistency index increased.

Flow behavior index (n):

The flow behavior index of all ketchup samples was less than 1.0 indicating that they were pseudoplastic fluids. One of the most important changes due to storage temperature was the significant increase in flow behavior index with increasing in storage temperature. These ketchup samples had the highest n, indicating that they were less pseudoplastic than control. The significant increase in flow behavior index indicated that a more closely packed structure was formed (**Aguilar *et al.*,(1991) and Alonso and Zapico (1996)**) .

Casson model (CA):

The CA model was developed for a system of interacting particles in a Newtonian medium. In addition, other assumptions such as the absence of Brownian motion and the formation of rigid rod like particles were made to relate the parameters of the equation and the structure of the fluid. Deviation from the assumed structure is one of the possible reasons for the partial applicability of the CA model. Another possible reason is that the model is not applicable at low shear rate.

In spite of the deviation of the CA model from data at low shear rates, it is a simple and useful method for estimating the yield point of tomato concentrates. **Rao *et al.* (1981)** showed that different experimental methods for determining yield point yielded different magnitudes. The CA model will provide yield point values in a consistent manner and the data necessary to use the model can be obtained unequivocally.

The Casson model equation was found to be a good model to describe the flow behavior of ketchups samples at storage condition Tables (5.10-12). Values of R^2 were ranged between 0.92 to 0.99. After 2-month storage at 5, 20 and 30 °C Casson model parameters were significantly affected by storage temperature and storage time. For 2-months storage resulted in significant increases ($P < 0.01$). These results were in agreement with **Harnanan *et al.* (2001).**

Casson yield point (τ_{0CA}):

The yield value for CA model was higher than HB model yield point values for various tomato ketchups at all storage temperature. Similar results had been reported for ketchup, mustard paste by **Ofoli *et al.* (1987)**, for mango pulp (**Bhattacharya, 1999**) and for guava pulp by **Harnanan *et al.* (2001)**. Thus yield point should be best determined by CA model. The yield point had been decreased with storage at 2-month for (Lidl, Kraft, Werder, Heinz, Americana, Heinz Egypt, and GSF tomato ketchups) but increased for Reichelt tomato ketchup with storage for 2-month , it can be attributed to many factors. These factors include the heterogeneity of the materials constituting the products, the difference in the product formulation between cold and hot breaks, the different homogenisation degree (**Castaldo *et al.* 1990**) and finally the difference among the products in their pectic content (**Bottiglieri *et al.* 1991**). On the other hand, τ_{0CA} had been decreased with increasing storage temperature.

Casson dynamic viscosity:

The casson viscosity for all tomato ketchups under studied decreased at all storage temperatures. Anyhow the values of these parameters were generally decreased with increasing of storage temperature. These parameters were (0.376, 0.363 and 0.348 Pa s), (0.213, 0.198 and 0.186 Pa s) and (0.896, 0.865 and 0.852 Pa s) at 0 °C temperature for Heinz, Reichelt and Americana tomato ketchups stored for 2-month at storage temperature 5, 20 and 30 °C, respectively. Similar results had been reported by **Saleh (1998).**

Table(5.10) Effect of 2-manth storage at 5 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	7.2377	27.4943	0.2847	0.9985	1.19012	1.0925	27.0506	0.3522	0.9380	7.5293	1.2400	37.1579
	10	4.2931	26.6768	0.2603	0.9989	0.86315	0.9275	24.1926	0.2866	0.9272	6.7520	1.0552	-59.0172
	20	2.4274	26.6665	0.2421	0.9989	0.7460	0.8374	22.8428	0.2485	0.9196	6.2772	0.9534	-25.7479
	30	12.3079	17.7606	0.2843	0.9989	0.6493	0.7808	26.0293	0.1728	0.9555	4.1139	0.8573	90.7338
	40	8.1747	15.3671	0.2739	0.9992	0.4547	0.6242	20.0635	0.1466	0.9482	3.5888	0.6902	-15.7217
	50	-3.2494	21.9800	0.2276	0.9994	0.4082	0.5944	13.0311	0.2251	0.8814	5.6363	0.6979	160.4104
Kraft	0	13.4626	22.8927	0.3129	0.9991	0.9298	1.1018	29.9151	0.3136	0.9554	6.3177	1.2253	64.7082
	10	6.9734	20.2424	0.2862	0.9991	0.6938	0.8260	21.7871	0.2477	0.9413	5.4330	0.9302	-60.3556
	20	5.4107	12.4101	0.2969	0.9990	0.4799	0.5412	14.4269	0.1591	0.9476	3.3668	0.6064	-112.3060
	30	5.6091	14.9411	0.2729	0.9990	0.4984	0.5811	16.9302	0.1558	0.9421	3.6663	0.6499	-95.8003
	40	5.5748	11.8548	0.2802	0.9994	0.3307	0.4866	14.4965	0.1303	0.9462	3.0014	0.5501	-70.1853
	50	5.0662	11.1688	0.2850	0.9997	0.2197	0.4656	13.4419	0.1252	0.9439	2.9004	0.5191	-2.9852
Werder	0	14.7265	19.0549	0.3796	0.9999	0.1557	1.2417	26.7728	0.4308	0.9615	7.1151	1.3778	-464.9149
	10	13.9623	16.9068	0.3791	0.9999	0.3106	1.1085	24.7306	0.3723	0.9650	6.0214	1.2265	-360.6926
	20	13.5564	15.3405	0.3753	0.9998	0.3917	0.9994	23.4950	0.3194	0.9673	5.1820	1.1022	-277.6627
	30	13.9675	14.1845	0.3736	0.9998	0.3263	0.9322	23.3103	0.2793	0.9691	4.6138	1.0227	-206.9962
	40	13.2307	13.0119	0.3766	0.9999	0.2136	0.8694	21.7728	0.2595	0.9693	4.2848	0.9526	-104.4038
	50	10.1195	8.7043	0.3852	0.9999	0.0981	0.6142	15.8137	0.1766	0.9701	2.9564	0.6690	-94.6894
Heinz	0	1.0601	31.2296	0.2596	0.9989	0.9985	1.0428	23.5431	0.3761	0.9129	8.5876	1.2067	282.2752
	10	2.7106	23.9599	0.2536	0.9983	0.9064	0.7975	20.6074	0.2502	0.9242	5.9342	0.9104	110.2833
	20	2.8095	18.2136	0.2524	0.9988	0.5836	0.6105	16.6054	0.1806	0.9265	4.4002	0.6930	-27.8408
	30	1.4824	19.8090	0.2328	0.9994	0.3988	0.5935	16.9034	0.1681	0.9159	4.4689	0.6743	-24.7046
	40	5.8374	14.6506	0.2612	0.9997	0.2574	0.5462	17.2530	0.1325	0.9387	3.4196	0.6074	25.2691
	50	4.6067	12.7455	0.2654	0.9996	0.2604	0.4787	14.4144	0.1235	0.9378	3.0763	0.5345	109.1991

Table(5.10) Continue : Effect of 2-manth storage at 5 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	A_{TH}
	°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	26.5465	19.3413	0.3258	0.9991	0.8302	1.1326	41.1941	0.2131	0.9731	4.4923	1.2176	-0.1391
	10	26.2470	17.5863	0.3159	0.9993	0.6158	1.0158	39.9364	0.1685	0.9725	3.8854	1.0867	20.3020
	20	23.8956	21.3168	0.2744	0.9994	0.5372	0.9932	41.3261	0.1523	0.9622	4.2768	1.0673	39.8854
	30	16.5115	23.1597	0.2632	0.9999	0.2513	0.9434	35.2327	0.1768	0.9495	4.9693	1.0283	61.7579
	40	10.1866	15.2805	0.2600	0.9999	0.0724	0.6079	22.5862	0.1146	0.9456	3.3171	0.6622	-55.4577
	50	6.9086	12.2757	0.2704	0.9999	0.1112	0.4955	16.5789	0.1097	0.9405	2.9774	0.5452	-34.1505
Americana Egypt	0	5.7031	22.4554	0.4151	0.9997	0.9756	1.5759	16.7582	0.8963	0.9440	12.2937	1.8390	-544.1442
	10	4.7327	20.5531	0.3947	0.9997	0.6972	1.3129	15.5030	0.7124	0.9387	10.5159	1.5321	-217.4532
	20	4.3300	18.3700	0.3882	0.9998	0.5691	1.1411	14.1925	0.6024	0.9382	9.0968	1.3291	-64.4602
	30	5.7919	15.6293	0.4029	0.9999	0.3690	1.0573	14.1690	0.5270	0.9487	7.6557	1.2152	-185.3135
	40	5.1926	13.9466	0.3998	0.9999	0.3052	0.9311	12.7513	0.4585	0.9483	0.9483	1.0696	-135.4192
	50	5.3336	10.6699	0.4104	0.9998	0.3159	0.7596	11.1209	0.3549	0.9576	4.9722	0.8634	-111.4733
Heinz Egypt	0	12.0134	22.6676	0.3106	0.9979	1.3587	1.0677	28.2048	0.3147	0.9559	6.1642	1.1926	234.5264
	10	9.2417	23.6028	0.2875	0.9982	1.1442	0.9795	26.6052	0.2836	0.9465	6.1178	1.0990	303.3880
	20	9.4329	23.2819	0.2820	0.9973	1.3207	0.9475	26.8100	0.2622	0.9466	5.8318	1.0606	163.5427
	30	6.0844	19.2271	0.2781	0.9966	1.1968	0.7529	20.3104	0.2215	0.9434	4.8483	0.8488	113.5566
	40	2.8967	26.3966	0.2399	0.9903	2.1975	0.8258	23.1561	0.2387	0.9335	5.6879	0.9405	-122.3736
	50	3.1847	20.4597	0.2581	0.9875	2.1837	0.7034	18.4159	0.2181	0.9367	4.8673	0.8031	-323.1215
G S F Egypt	0	2.269	24.8270	0.3211	0.9993	0.8824	1.0890	14.7966	0.5685	0.9054	10.3450	1.2965	222.7525
	10	2.2700	22.6566	0.2928	0.9985	1.0428	0.8953	17.5428	0.3609	0.9237	7.2156	1.0396	137.3806
	20	7.1172	20.4044	0.2795	0.9981	0.9704	0.8103	22.2124	0.2335	0.9437	5.1681	0.9111	56.2436
	30	9.4633	17.1574	0.2778	0.9994	0.4534	0.7113	22.6834	0.1684	0.9485	4.0941	0.7861	52.8629
	40	13.9831	12.7241	0.2977	0.9999	0.1489	0.6410	24.0033	0.1169	0.9615	2.9639	0.6920	49.1040
	50	10.1039	11.9536	0.2796	0.9999	0.1157	0.5342	19.6111	0.1020	0.9544	2.7074	0.5810	23.8472

Table(5.11) Effect of 2-manth storage at 20 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	8.6208	24.4257	0.2954	0.9986	1.08149	1.0382	26.1236	0.3262	0.9442	6.7794	1.1713	-11.4956
	10	4.1786	22.4572	0.2717	0.9988	0.80546	0.8266	20.5865	0.2668	0.9302	5.9906	0.9414	-96.9962
	20	15.3102	18.6956	0.2985	0.9991	0.6844	0.8923	29.5477	0.1975	0.9599	4.4872	0.9761	30.6665
	30	1.8014	26.2798	0.2375	0.9987	0.7723	0.8026	22.0072	0.2374	0.9176	6.0711	0.9146	42.5256
	40	8.3114	15.6339	0.2737	0.9993	0.4159	0.6345	20.4144	0.1488	0.9476	3.6668	0.7015	8.1830
	50	-3.2546	19.2180	0.2271	0.9994	0.3498	0.5144	10.8855	0.2012	0.8761	5.0091	0.6060	123.3062
Kraft	0	12.7591	26.1474	0.2994	0.9990	1.0126	1.1657	31.8319	0.3324	0.9502	7.0216	1.3013	-26.4897
	10	9.8446	19.3248	0.2979	0.9992	0.6725	0.8604	24.0379	0.2389	0.9503	5.1361	0.9586	-84.0807
	20	5.8480	15.9879	0.2812	0.9991	0.5165	0.6422	17.7322	0.1829	0.9419	4.1363	0.7204	-109.8407
	30	5.9790	15.6173	0.2727	0.9990	0.5045	0.6081	17.8391	0.1616	0.9422	3.8210	0.6796	-92.1401
	40	6.1189	12.6735	0.2828	0.9993	0.3692	0.5273	15.6963	0.1366	0.9469	3.1682	0.5864	-50.8156
	50	5.3033	10.7357	0.2890	0.9996	0.2534	0.4593	13.3317	0.1223	0.9469	2.7838	0.5110	17.7968
Werder	0	16.8002	18.0573	0.3903	0.9999	0.1673	1.2576	28.1414	0.4177	0.9664	6.6878	1.3848	-430.0261
	10	15.0601	17.0283	0.3811	0.9999	0.3093	1.1355	25.9323	0.3721	0.9668	5.9780	1.2527	-360.2381
	20	13.7075	15.6806	0.3726	0.9998	0.4162	1.0092	23.9228	0.3204	0.9670	5.2460	1.1133	-289.4693
	30	14.2969	14.2362	0.3752	0.9998	0.3377	0.9443	23.6555	0.2820	0.9698	4.6227	1.0351	-181.0486
	40	13.5130	12.3829	0.3786	0.9999	0.1732	0.8431	21.6730	0.2440	0.9705	4.0402	0.9207	-117.5935
	50	9.2382	9.3887	0.3742	0.9999	0.06293	0.6184	15.4384	0.1854	0.9659	3.2026	0.6781	-97.7736
Heinz	0	4.8506	29.2734	0.2738	0.9990	0.9668	1.0814	25.9575	0.3627	0.9271	8.0841	1.2359	328.0785
	10	0.9964	25.3066	0.2453	0.9983	0.9052	0.7931	19.9220	0.2582	0.9162	6.2240	0.9110	93.8543
	20	1.4920	22.8518	0.2362	0.9985	0.7231	0.6931	19.0741	0.2043	0.9186	5.2089	0.7898	13.6659
	30	1.2787	21.7987	0.2299	0.9994	0.4042	0.6412	18.2931	0.1815	0.9136	4.8804	0.7289	5.8576
	40	4.2637	15.8660	0.2509	0.9996	0.2818	0.5464	16.6285	0.1403	0.9309	3.6686	0.6121	18.0847
	50	-3.5803	20.0764	0.2122	0.9992	0.3884	0.4976	11.7027	0.1773	0.8787	4.6727	0.5824	146.5641

Table(5.11) Continue : Effect of 2-manth storage at 20 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

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	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	32.9374	21.9140	0.3099	0.9986	1.0754	1.2425	50.1322	0.1975	0.9733	4.6187	1.3281	-50.6177
	10	31.1742	18.8829	0.3105	0.9992	0.7016	1.1007	46.0952	0.1629	0.9736	3.9628	1.1719	66.1055
	20	18.8421	20.1333	0.2804	0.9995	0.4972	0.9208	34.9464	0.1662	0.9596	4.3272	0.9977	29.0295
	30	13.8231	21.2604	0.2557	0.9998	0.2450	0.8284	31.1193	0.1546	0.9471	4.4484	0.9045	15.7255
	40	8.8502	14.4710	0.2661	0.9999	0.0641	0.5813	20.3986	0.1201	0.9432	3.3410	0.6371	-50.0444
	50	7.6689	13.4444	0.2718	0.9998	0.1815	0.5467	18.2488	0.1214	0.9396	3.3106	0.6016	-72.3200
Americana Egypt	0	5.3248	21.3415	0.4132	0.9997	0.9827	1.4842	14.9381	0.8652	0.9452	10.2548	1.7336	-452.3281
	10	4.6231	19.7451	0.3908	0.9999	0.6728	1.2404	13.8183	0.6927	0.9508	8.0715	1.4497	-342.5142
	20	4.3128	16.5428	0.3714	0.9998	0.5214	0.9581	13.0921	0.5412	0.94381	7.1022	1.2045	-201.3662
	30	5.3251	13.4252	0.3827	0.9998	0.3108	0.8355	12.5998	0.4637	0.9367	4.3012	1.0731	-123.5821
	40	5.2743	11.7415	0.3712	0.9999	0.3041	0.7016	11.637	0.4114	0.9607	3.3691	0.9654	-94.6552
	50	4.9582	10.5348	0.3701	0.9997	0.2981	0.6288	10.2105	0.3527	0.9545	3.1514	0.8343	-87.8276
Heinz Egypt	0	9.8713	26.5633	0.2808	0.9974	1.4759	1.0667	29.5831	0.3030	0.9468	6.6121	1.1976	365.9242
	10	9.5289	31.3707	0.2530	0.9984	1.1369	1.1011	33.9802	0.2776	0.9380	7.0109	1.2317	402.1202
	20	5.4912	25.3539	0.2511	0.9985	0.8753	0.8607	25.0287	0.2348	0.9309	5.8939	0.9699	171.1901
	30	1.7001	23.1800	0.2359	0.9985	0.7250	0.7039	19.6165	0.2044	0.9181	5.2830	0.801	278.9621
	40	0.6021	20.6571	0.2287	0.9976	0.7831	0.5982	16.6217	0.1754	0.9164	4.5406	0.6831	204.6912
	50	-1.0075	27.4151	0.2192	0.9954	1.3523	0.7422	20.3257	0.2231	0.9134	5.7670	0.8523	-557.2044
G S F Egypt	0	-0.2992	26.7499	0.2927	0.9988	1.09233	1.0267	17.0133	0.4746	0.9067	9.3676	1.213	168.4350
	10	-2.3013	27.0871	0.2541	0.9979	1.1434	0.8499	16.7093	0.3504	0.8988	7.7494	1.0014	112.1007
	20	0.2145	24.8458	0.2390	0.9974	1.0518	0.7490	18.8976	0.2440	0.9152	5.9106	0.8624	58.1157
	30	1.0727	23.6873	0.2262	0.9982	0.7748	0.6820	19.6105	0.1919	0.9175	5.0804	0.776	27.0200
	40	4.7117	17.8031	0.2428	0.9994	0.3789	0.5917	18.7951	0.1442	0.9315	3.8896	0.6614	25.1326
	50	5.6985	14.8542	0.2544	0.9998	0.1949	0.5363	17.4256	0.1254	0.9367	3.3623	0.5953	27.8155

Table(5.12) Effect of 2-manth storage at 30 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	10.1785	22.7707	0.3048	0.9987	1.0522	1.0286	26.4231	0.3139	0.9498	6.3543	1.1541	21.3276
	10	2.2422	25.9233	0.2592	0.9987	0.8749	0.8777	21.2811	0.2940	0.9205	6.7995	1.0071	-70.9892
	20	1.9156	24.6231	0.2471	0.9989	0.7090	0.7875	20.4871	0.2460	0.9183	6.0382	0.8999	-42.2246
	30	13.6688	17.9959	0.2880	0.9992	0.5695	0.8146	27.5825	0.1757	0.9569	4.1931	0.8918	44.9175
	40	7.6206	17.1935	0.2678	0.9992	0.4723	0.6664	20.9125	0.1624	0.9436	4.0271	0.7401	32.2862
	50	-3.5174	20.5023	0.2307	0.9997	0.2701	0.5580	11.4327	0.2242	0.8710	5.5647	0.6587	144.7232
Kraft	0	9.5986	23.5458	0.2987	0.9989	0.9653	1.0278	26.5468	0.3130	0.9468	6.5121	1.155	-22.8503
	10	5.8757	20.2070	0.2824	0.9990	0.7258	0.8006	20.6313	0.2471	0.9382	5.4313	0.905	-94.3997
	20	5.6363	15.4002	0.2851	0.9990	0.5352	0.6288	16.9795	0.1835	0.9426	4.0609	0.7063	-84.7284
	30	5.6038	14.9360	0.2754	0.9991	0.4720	0.5870	16.8633	0.1599	0.9418	3.7274	0.6569	-95.3599
	40	5.8373	11.9932	0.2861	0.9993	0.3508	0.5062	14.8448	0.1334	0.9473	3.0464	0.5633	-18.7982
	50	6.4524	10.9799	0.2987	0.9996	0.2589	0.4990	14.6121	0.1306	0.9510	2.9040	0.553	21.9536
Werder	0	15.6748	19.0157	0.3876	0.9999	0.1852	1.2900	27.5304	0.4494	0.9634	7.2389	1.4282	-423.6683
	10	17.2031	17.4961	0.3911	0.9999	0.3135	1.2316	28.2171	0.3996	0.9699	6.1840	1.3534	-322.3023
	20	14.5052	16.0649	0.3765	0.9998	0.4153	1.0547	24.9027	0.3352	0.9679	5.4155	1.1621	-237.1102
	30	14.7338	15.1816	0.3787	0.9998	0.3840	1.0157	24.5805	0.3141	0.9696	5.0428	1.1156	-149.7133
	40	11.1761	10.8928	0.3788	0.9999	0.09757	0.7351	18.3986	0.2111	0.9682	3.5911	0.7892	-124.6924
	50	9.9459	9.6035	0.3777	0.9999	0.0762	0.6463	16.2654	0.1915	0.9674	3.2667	0.7071	-87.5661
Heinz	0	2.3906	27.2054	0.2702	0.9988	0.9702	0.9681	21.7624	0.3482	0.9200	7.6866	1.1164	257.8467
	10	1.3348	24.5275	0.2493	0.9983	0.8956	0.7865	19.5724	0.2580	0.9179	6.1362	0.9032	91.5290
	20	1.0858	22.9379	0.2363	0.9985	0.7235	0.6919	18.6584	0.2090	0.9167	5.2931	0.7905	64.0159
	30	0.4599	19.1484	0.2316	0.9992	0.4374	0.5609	15.2205	0.1686	0.9113	4.3997	0.6412	-46.4873
	40	3.1360	14.7751	0.2517	0.9996	0.2642	0.5023	14.5151	0.1378	0.9270	3.5259	0.5658	-9.8105
	50	3.3707	14.4372	0.2574	0.9996	0.2597	0.5061	14.4038	0.1410	0.9286	3.5391	0.5701	120.6751

Table(5.12) Continue : Effect of 2-manth storage at 30 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

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	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	35.4859	17.0383	0.3470	0.9991	0.8340	1.1971	48.2461	0.1861	0.9811	3.7531	1.2678	20.1139
	10	29.1341	17.8372	0.3138	0.9992	0.6731	1.0480	43.1516	0.1600	0.9739	3.7983	1.1170	-15.7870
	20	27.8900	21.8905	0.2750	0.9995	0.5128	1.0556	45.9460	0.1479	0.9640	4.3004	1.1287	77.4887
	30	18.4705	21.5170	0.2566	0.9999	0.2241	0.8861	36.2834	0.1416	0.9525	4.2988	0.9578	-54.2223
	40	8.8306	12.0826	0.2742	0.9999	0.1180	0.5154	18.4688	0.1025	0.9471	2.8342	0.5624	-67.5120
	50	8.7081	12.4517	0.2815	0.9998	0.2067	0.5423	18.4873	0.1159	0.9449	3.1134	0.5935	-38.5616
Americana Egypt	0	4.7439	20.7814	0.4164	0.9996	1.0434	1.4615	14.8243	0.8523	0.9429	11.5801	1.7115	-382.4189
	10	4.5684	17.6316	0.4001	0.9997	0.6672	1.1587	13.7278	0.6254	0.9422	9.0341	1.3487	-255.5503
	20	4.1669	15.9946	0.3880	0.9998	0.5042	0.9966	12.8309	0.5152	0.9403	7.7884	1.1577	-69.5106
	30	5.1345	13.8317	0.3983	0.9999	0.3358	0.9173	12.6605	0.4498	0.9484	6.6317	1.0537	-146.4402
	40	4.5600	12.4241	0.3941	0.9999	0.2818	0.8085	11.4089	0.3917	0.9475	5.8658	0.9286	-85.0721
	50	3.8816	11.3655	0.3888	0.9999	0.2727	0.7199	10.1995	0.3490	0.9455	5.3083	0.8283	-53.5655
Heinz Egypt	0	15.2919	23.8272	0.3185	0.9976	1.6101	1.1859	32.2880	0.3356	0.9612	6.3846	1.3168	497.7099
	10	10.2463	22.8427	0.2907	0.9980	1.1848	0.9737	27.0967	0.2735	0.9497	5.8643	1.0889	313.5611
	20	9.4567	22.1214	0.2868	0.9976	1.2133	0.9233	25.8654	0.2578	0.9478	5.6433	1.0329	146.8578
	30	6.0853	21.2003	0.2690	0.9970	1.1837	0.7926	22.0040	0.2266	0.9405	5.1681	0.8932	198.4469
	40	1.9946	20.5668	0.2530	0.9963	1.1494	0.6793	17.3199	0.2168	0.9265	5.0197	0.7776	321.7711
	50	3.8198	12.9145	0.2964	0.9917	1.4210	0.5439	12.8991	0.1830	0.9482	3.5348	0.6193	-84.7089
G S F Egypt	0	-0.4153	28.8684	0.2871	0.9989	1.0800	1.0788	18.5453	0.4864	0.9053	9.8292	1.2725	239.2946
	10	-1.2415	28.3701	0.2559	0.9981	1.1666	0.9094	18.8543	0.3570	0.9051	7.9599	1.0644	123.2946
	20	-0.4069	26.2608	0.2354	0.9976	1.0417	0.7724	19.3854	0.2534	0.9117	6.2124	0.8905	60.8137
	30	1.16050	23.2366	0.2260	0.9982	0.7508	0.6695	19.3756	0.1869	0.9179	4.9646	0.7613	30.5699
	40	3.1900	19.7490	0.2325	0.9994	0.3958	0.6081	18.8559	0.1541	0.9238	4.2380	0.6836	30.3635
	50	5.0725	15.8563	0.2510	0.9999	0.1711	0.5545	17.5539	0.1348	0.9323	3.6280	0.618	53.3508

Table(5.16) Effect of 6-month storage at 5 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	-1.8241	29.0104	0.2589	0.9982	1.1844	0.9375	18.4970	0.3840	0.9020	8.4207	1.1020	51.6159
	10	-4.8166	27.2208	0.2239	0.9989	0.6624	0.7151	15.3166	0.2775	0.8787	6.8874	0.8430	-3.2124
	20	-5.8034	27.0563	0.2237	0.9998	0.2624	0.7000	13.9995	0.2886	0.8561	7.3527	0.8306	85.1022
	30	-0.9692	18.9126	0.2747	0.9996	0.3766	0.6604	11.8662	0.2888	0.8832	6.5089	0.7777	166.9277
	40	0.5931	15.5285	0.2947	0.9996	0.3542	0.6092	10.8873	0.2643	0.9010	5.6027	0.7124	152.3528
	50	1.4938	13.1448	0.3067	0.9997	0.3068	0.5546	10.1540	0.2339	0.9096	4.8755	0.6437	136.3138
Kraft	0	-6.9512	33.0869	0.2393	0.9980	1.2294	0.9265	16.1504	0.4261	0.8716	9.5921	1.1123	47.3549
	10	-9.5121	31.9419	0.2182	0.9984	0.9276	0.7774	13.3070	0.3670	0.8459	8.7016	0.9421	-52.8935
	20	-9.8514	30.0593	0.2126	0.9992	0.5902	0.7016	11.6673	0.3394	0.8286	8.2333	0.8541	-49.0024
	30	-4.4607	22.8603	0.2259	0.9991	0.5110	0.6024	12.2323	0.2451	0.8723	6.0043	0.7137	-75.6590
	40	-6.2467	24.0525	0.2163	0.9994	0.4135	0.5888	11.2998	0.2531	0.8523	6.3128	0.7043	31.1286
	50	-2.9681	19.3769	0.2423	0.9997	0.2863	0.5617	10.7944	0.2373	0.8729	5.6536	0.6653	143.8319
Werder	0	10.8533	18.6590	0.3722	0.9999	0.1263	1.1444	22.4987	0.4344	0.9534	7.3376	1.2846	-424.1740
	10	5.5794	18.7013	0.3493	0.9998	0.3776	0.9901	17.1674	0.4247	0.9385	7.4267	1.1364	-354.7249
	20	5.5027	16.9455	0.3437	0.9998	0.3970	0.8800	16.2362	0.3601	0.9409	6.3976	1.0061	-243.6571
	30	5.3511	15.1200	0.3428	0.9998	0.3046	0.7866	15.0158	0.3130	0.9419	5.6265	0.8967	-85.5486
	40	5.4980	12.6459	0.3473	0.9999	0.1675	0.6809	13.6458	0.2588	0.9459	4.6597	0.7711	-80.1431
	50	8.6819	9.0281	0.3856	0.9999	0.1033	0.6199	14.4488	0.1982	0.9659	3.2788	0.6811	-58.0608
Heinz	0	-6.8437	30.5805	0.2419	0.9978	1.2290	0.8632	14.1665	0.4152	0.8674	9.1661	1.0419	72.0552
	10	-13.7952	41.7414	0.1962	0.9976	1.2696	0.8924	17.4768	0.3823	0.8462	9.7027	1.0740	155.2381
	20	-5.4294	31.3443	0.2084	0.9985	0.8087	0.7641	18.6866	0.2620	0.8848	6.9425	0.8914	85.6017
	30	-18.1348	34.0080	0.1674	0.9993	0.5638	0.5538	15.4958	0.3096	0.8106	8.7167	0.9026	101.6590
	40	-14.5369	36.1742	0.1743	0.9997	0.3371	0.6619	13.3969	0.2784	0.8095	7.7676	0.7986	183.0924
	50	6.9887	13.9132	0.2896	0.9999	0.0428	0.5979	17.3874	0.1585	0.9417	3.7718	0.6644	171.0475

Table(5.12) Continue : Effect of 2-manth storage at 30 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	35.4859	17.0383	0.3470	0.9991	0.8340	1.1971	48.2461	0.1861	0.9811	3.7531	1.2678	20.1139
	10	29.1341	17.8372	0.3138	0.9992	0.6731	1.0480	43.1516	0.1600	0.9739	3.7983	1.1170	-15.7870
	20	27.8900	21.8905	0.2750	0.9995	0.5128	1.0556	45.9460	0.1479	0.9640	4.3004	1.1287	77.4887
	30	18.4705	21.5170	0.2566	0.9999	0.2241	0.8861	36.2834	0.1416	0.9525	4.2988	0.9578	-54.2223
	40	8.8306	12.0826	0.2742	0.9999	0.1180	0.5154	18.4688	0.1025	0.9471	2.8342	0.5624	-67.5120
	50	8.7081	12.4517	0.2815	0.9998	0.2067	0.5423	18.4873	0.1159	0.9449	3.1134	0.5935	-38.5616
Americana Egypt	0	4.7439	20.7814	0.4164	0.9996	1.0434	1.4615	14.8243	0.8523	0.9429	11.5801	1.7115	-382.4189
	10	4.5684	17.6316	0.4001	0.9997	0.6672	1.1587	13.7278	0.6254	0.9422	9.0341	1.3487	-255.5503
	20	4.1669	15.9946	0.3880	0.9998	0.5042	0.9966	12.8309	0.5152	0.9403	7.7884	1.1577	-69.5106
	30	5.1345	13.8317	0.3983	0.9999	0.3358	0.9173	12.6605	0.4498	0.9484	6.6317	1.0537	-146.4402
	40	4.5600	12.4241	0.3941	0.9999	0.2818	0.8085	11.4089	0.3917	0.9475	5.8658	0.9286	-85.0721
	50	3.8816	11.3655	0.3888	0.9999	0.2727	0.7199	10.1995	0.3490	0.9455	5.3083	0.8283	-53.5655
Heinz Egypt	0	15.2919	23.8272	0.3185	0.9976	1.6101	1.1859	32.2880	0.3356	0.9612	6.3846	1.3168	497.7099
	10	10.2463	22.8427	0.2907	0.9980	1.1848	0.9737	27.0967	0.2735	0.9497	5.8643	1.0889	313.5611
	20	9.4567	22.1214	0.2868	0.9976	1.2133	0.9233	25.8654	0.2578	0.9478	5.6433	1.0329	146.8578
	30	6.0853	21.2003	0.2690	0.9970	1.1837	0.7926	22.0040	0.2266	0.9405	5.1681	0.8932	198.4469
	40	1.9946	20.5668	0.2530	0.9963	1.1494	0.6793	17.3199	0.2168	0.9265	5.0197	0.7776	321.7711
	50	3.8198	12.9145	0.2964	0.9917	1.4210	0.5439	12.8991	0.1830	0.9482	3.5348	0.6193	-84.7089
G S F Egypt	0	-0.4153	28.8684	0.2871	0.9989	1.0800	1.0788	18.5453	0.4864	0.9053	9.8292	1.2725	239.2946
	10	-1.2415	28.3701	0.2559	0.9981	1.1666	0.9094	18.8543	0.3570	0.9051	7.9599	1.0644	123.2946
	20	-0.4069	26.2608	0.2354	0.9976	1.0417	0.7724	19.3854	0.2534	0.9117	6.2124	0.8905	60.8137
	30	1.16050	23.2366	0.2260	0.9982	0.7508	0.6695	19.3756	0.1869	0.9179	4.9646	0.7613	30.5699
	40	3.1900	19.7490	0.2325	0.9994	0.3958	0.6081	18.8559	0.1541	0.9238	4.2380	0.6836	30.3635
	50	5.0725	15.8563	0.2510	0.9999	0.1711	0.5545	17.5539	0.1348	0.9323	3.6280	0.618	53.3508

Table(5.16) Effect of 6-month storage at 5 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	-1.8241	29.0104	0.2589	0.9982	1.1844	0.9375	18.4970	0.3840	0.9020	8.4207	1.1020	51.6159
	10	-4.8166	27.2208	0.2239	0.9989	0.6624	0.7151	15.3166	0.2775	0.8787	6.8874	0.8430	-3.2124
	20	-5.8034	27.0563	0.2237	0.9998	0.2624	0.7000	13.9995	0.2886	0.8561	7.3527	0.8306	85.1022
	30	-0.9692	18.9126	0.2747	0.9996	0.3766	0.6604	11.8662	0.2888	0.8832	6.5089	0.7777	166.9277
	40	0.5931	15.5285	0.2947	0.9996	0.3542	0.6092	10.8873	0.2643	0.9010	5.6027	0.7124	152.3528
	50	1.4938	13.1448	0.3067	0.9997	0.3068	0.5546	10.1540	0.2339	0.9096	4.8755	0.6437	136.3138
Kraft	0	-6.9512	33.0869	0.2393	0.9980	1.2294	0.9265	16.1504	0.4261	0.8716	9.5921	1.1123	47.3549
	10	-9.5121	31.9419	0.2182	0.9984	0.9276	0.7774	13.3070	0.3670	0.8459	8.7016	0.9421	-52.8935
	20	-9.8514	30.0593	0.2126	0.9992	0.5902	0.7016	11.6673	0.3394	0.8286	8.2333	0.8541	-49.0024
	30	-4.4607	22.8603	0.2259	0.9991	0.5110	0.6024	12.2323	0.2451	0.8723	6.0043	0.7137	-75.6590
	40	-6.2467	24.0525	0.2163	0.9994	0.4135	0.5888	11.2998	0.2531	0.8523	6.3128	0.7043	31.1286
	50	-2.9681	19.3769	0.2423	0.9997	0.2863	0.5617	10.7944	0.2373	0.8729	5.6536	0.6653	143.8319
Werder	0	10.8533	18.6590	0.3722	0.9999	0.1263	1.1444	22.4987	0.4344	0.9534	7.3376	1.2846	-424.1740
	10	5.5794	18.7013	0.3493	0.9998	0.3776	0.9901	17.1674	0.4247	0.9385	7.4267	1.1364	-354.7249
	20	5.5027	16.9455	0.3437	0.9998	0.3970	0.8800	16.2362	0.3601	0.9409	6.3976	1.0061	-243.6571
	30	5.3511	15.1200	0.3428	0.9998	0.3046	0.7866	15.0158	0.3130	0.9419	5.6265	0.8967	-85.5486
	40	5.4980	12.6459	0.3473	0.9999	0.1675	0.6809	13.6458	0.2588	0.9459	4.6597	0.7711	-80.1431
	50	8.6819	9.0281	0.3856	0.9999	0.1033	0.6199	14.4488	0.1982	0.9659	3.2788	0.6811	-58.0608
Heinz	0	-6.8437	30.5805	0.2419	0.9978	1.2290	0.8632	14.1665	0.4152	0.8674	9.1661	1.0419	72.0552
	10	-13.7952	41.7414	0.1962	0.9976	1.2696	0.8924	17.4768	0.3823	0.8462	9.7027	1.0740	155.2381
	20	-5.4294	31.3443	0.2084	0.9985	0.8087	0.7641	18.6866	0.2620	0.8848	6.9425	0.8914	85.6017
	30	-18.1348	34.0080	0.1674	0.9993	0.5638	0.5538	15.4958	0.3096	0.8106	8.7167	0.9026	101.6590
	40	-14.5369	36.1742	0.1743	0.9997	0.3371	0.6619	13.3969	0.2784	0.8095	7.7676	0.7986	183.0924
	50	6.9887	13.9132	0.2896	0.9999	0.0428	0.5979	17.3874	0.1585	0.9417	3.7718	0.6644	171.0475

Table(5.17) Continue: Effect of 6-month storage at 20 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	7.3137	22.9130	0.2547	0.9988	0.7406	0.8136	25.1598	0.2041	0.9383	5.1596	0.9089	122.6129
	10	1.9051	27.6892	0.2323	0.9995	0.4788	0.8261	23.4825	0.2344	0.9143	6.2723	0.9384	29.2092
	20	-4.0723	30.8508	0.2083	0.9998	0.2713	0.7644	20.0275	0.2426	0.8835	6.8242	0.8837	0.4441
	30	-4.2375	28.4630	0.2192	0.9999	0.1068	0.7387	17.3308	0.2621	0.8718	7.0949	0.8617	50.7227
	40	-2.5409	18.9171	0.2387	0.9998	0.2258	0.5425	11.1726	0.2155	0.8650	5.5045	0.6376	44.7322
	50	-0.3719	17.3836	0.2578	0.9995	0.3427	0.5661	12.1077	0.2144	0.8834	5.3493	0.6577	62.8338
Americana Egypt	0	10.3250	20.6422	0.3722	0.9999	0.2056	1.2492	22.9488	0.5029	0.9499	8.4095	1.4118	-769.2083
	10	9.5525	17.2766	0.3771	0.9999	0.0967	1.0765	20.1082	0.4257	0.9520	7.0769	1.2119	-449.7635
	20	8.2386	14.1071	0.3932	0.9999	0.1742	0.9450	16.4993	0.3912	0.9568	6.0172	1.0643	-511.7590
	30	7.7427	12.2420	0.3975	0.9999	0.2089	0.8410	14.8810	0.3434	0.9600	5.1524	0.9443	-331.5882
	40	8.1686	10.0540	0.4131	0.9999	0.2478	0.7555	13.9379	0.2949	0.9684	4.1121	0.8398	-269.3627
	50	6.8345	9.1261	0.4065	0.9998	0.2705	0.6617	12.1206	0.2611	0.9667	3.6997	0.7381	-151.1370
Heinz Egypt	0	4.9444	39.6274	0.2488	0.9970	1.9345	1.2957	35.0233	0.3875	0.9291	9.2349	1.4745	534.8268
	10	-10.855	48.772	0.1914	0.9988	0.9942	1.0690	27.8019	0.3460	0.8769	9.8046	1.2443	363.4060
	20	-14.8021	46.7446	0.1829	0.9993	0.6743	0.9372	21.8606	0.3425	0.8478	9.6957	1.1084	279.3489
	30	-10.6889	39.2327	0.2031	0.9976	1.2519	0.8928	18.8932	0.3552	0.8635	9.0704	1.0622	246.8830
	40	-10.6521	34. 9745	0.1988	0.9974	1.1310	0.7672	15.6207	0.3171	0.8550	8.0695	0.9184	259.6366
	50	-12.0452	33.0132	0.1834	0.9976	0.9077	0.6478	13.1503	0.2711	0.8368	7.1572	0.7802	197.5803
G S F Egypt	0	-1.0882	24.7077	0.2892	0.9987	1.0109	0.9250	14.8821	0.4383	0.9016	8.6858	1.0979	-41.3662
	10	-1.8552	27.2569	0.2502	0.9977	1.1861	0.8442	17.5942	0.3310	0.9028	7.4574	0.9896	146.1422
	20	-12.1265	35.3254	0.1851	0.9967	1.1510	0.7072	14.9916	0.2844	0.8499	7.4824	0.8473	53.2270
	30	-17.3870	40.1694	0.1555	0.9987	0.6468	0.6482	14.9393	0.2439	0.8212	7.1874	0.7751	56.2347
	40	-14.3392	32.3950	0.1605	0.9996	0.2818	0.5350	11.2610	0.2187	0.8006	6.3321	0.6452	67.8882
	50	-16.4422	34.9791	0.1544	0.9998	0.2119	0.5478	11.3550	0.2279	0.7851	6.7013	0.6632	69.6273

Table(5.18) Effect of 6-month storage at 30 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	-2.7603	32.4756	0.2501	0.9983	1.2147	0.9998	20.4163	0.3991	0.8989	9.0224	1.1742	-7.0309
	10	-6.2628	35.3795	0.2240	0.9988	0.9201	0.9299	19.9277	0.3605	0.8801	8.9079	1.0958	-47.5424
	20	-8.9196	33.3554	0.2128	0.9989	0.7714	0.7995	15.6297	0.3393	0.8562	8.4507	0.9562	-12.4805
	30	-8.2502	29.7850	0.2126	0.9992	0.5841	0.7104	13.5750	0.3074	0.8500	7.6759	0.8517	25.6895
	40	-5.0511	25.0991	0.2333	0.9998	0.2736	0.6844	12.8618	0.2962	0.8599	7.2082	0.8152	133.7332
	50	-3.3686	21.0602	0.2511	0.9998	0.2450	0.6357	11.2165	0.2861	0.8613	6.7484	0.7565	177.3152
Kraft	0	-2.3848	27.3009	0.2585	0.9986	0.9485	0.8739	16.6528	0.3688	0.8961	8.1095	1.0310	-115.6691
	10	-6.8833	29.4976	0.2283	0.9988	0.7940	0.7753	14.2035	0.3444	0.8633	8.1410	0.9288	39.4313
	20	-6.8257	25.9723	0.2241	0.9988	0.6811	0.6607	11.7083	0.3023	0.8543	7.1728	0.7956	-96.4177
	30	-5.1561	20.8581	0.2280	0.9990	0.5026	0.5445	9.6402	0.2487	0.8562	5.8782	0.6548	-57.4613
	40	-3.0786	18.7543	0.2454	0.9998	0.2330	0.5498	10.0607	0.2416	0.8683	5.6773	0.6540	21.7184
	50	-1.2182	15.3567	0.2733	0.9999	0.1535	0.5284	9.0952	0.2394	0.8810	5.2915	0.6255	145.0700
Werder	0	3.9215	15.4975	0.3753	0.9999	0.3160	0.9119	12.6868	0.4511	0.9317	7.4506	1.0564	1.0231
	10	3.1744	14.7493	0.3554	0.9999	0.0780	0.7896	11.9331	0.3738	0.9264	6.5786	0.9155	-209.4090
	20	8.1327	11.7998	0.3830	0.9999	0.0731	0.7698	15.4144	0.2854	0.9592	4.6196	0.8590	-127.3629
	30	7.6990	10.1833	0.3876	0.9999	0.0576	0.6839	13.9750	0.2482	0.9614	3.9778	0.7604	-72.7399
	40	4.2503	10.9964	0.3593	0.9999	0.0963	0.6177	11.0303	0.2569	0.9430	4.4430	0.7039	-40.5973
	50	6.2757	7.2531	0.4053	0.9999	0.1123	0.5317	10.6003	0.1948	0.9650	2.9722	0.5882	1.2789
Heinz	0	1.8216	27.4815	0.2686	0.9988	0.9440	0.965	21.3540	0.3527	0.9172	7.8121	1.1151	294.9590
	10	-7.7440	30.5158	0.2146	0.9977	1.0407	0.7424	14.6754	0.3121	0.8660	7.6119	0.8869	78.6101
	20	-0.3756	27.8413	0.2267	0.9989	0.6982	0.7871	21.0951	0.2407	0.9074	6.3160	0.9023	156.8945
	30	-15.0661	36.6743	0.1763	0.9993	0.5111	0.6753	13.0414	0.2958	0.8088	8.0247	0.8190	93.4156
	40	-11.5607	30.0806	0.1870	0.9995	0.4009	0.5961	11.0441	0.2684	0.8127	7.0853	0.7232	162.5780
	50	5.5125	13.6903	0.2850	0.9998	0.2107	0.5638	15.6874	0.1585	0.9401	3.6664	0.6307	208.8800

Table(5.17) Continue: Effect of 6-month storage at 20 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	$Pa.s^n$	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	7.3137	22.9130	0.2547	0.9988	0.7406	0.8136	25.1598	0.2041	0.9383	5.1596	0.9089	122.6129
	10	1.9051	27.6892	0.2323	0.9995	0.4788	0.8261	23.4825	0.2344	0.9143	6.2723	0.9384	29.2092
	20	-4.0723	30.8508	0.2083	0.9998	0.2713	0.7644	20.0275	0.2426	0.8835	6.8242	0.8837	0.4441
	30	-4.2375	28.4630	0.2192	0.9999	0.1068	0.7387	17.3308	0.2621	0.8718	7.0949	0.8617	50.7227
	40	-2.5409	18.9171	0.2387	0.9998	0.2258	0.5425	11.1726	0.2155	0.8650	5.5045	0.6376	44.7322
	50	-0.3719	17.3836	0.2578	0.9995	0.3427	0.5661	12.1077	0.2144	0.8834	5.3493	0.6577	62.8338
Americana Egypt	0	10.3250	20.6422	0.3722	0.9999	0.2056	1.2492	22.9488	0.5029	0.9499	8.4095	1.4118	-769.2083
	10	9.5525	17.2766	0.3771	0.9999	0.0967	1.0765	20.1082	0.4257	0.9520	7.0769	1.2119	-449.7635
	20	8.2386	14.1071	0.3932	0.9999	0.1742	0.9450	16.4993	0.3912	0.9568	6.0172	1.0643	-511.7590
	30	7.7427	12.2420	0.3975	0.9999	0.2089	0.8410	14.8810	0.3434	0.9600	5.1524	0.9443	-331.5882
	40	8.1686	10.0540	0.4131	0.9999	0.2478	0.7555	13.9379	0.2949	0.9684	4.1121	0.8398	-269.3627
	50	6.8345	9.1261	0.4065	0.9998	0.2705	0.6617	12.1206	0.2611	0.9667	3.6997	0.7381	-151.1370
Heinz Egypt	0	4.9444	39.6274	0.2488	0.9970	1.9345	1.2957	35.0233	0.3875	0.9291	9.2349	1.4745	534.8268
	10	-10.855	48.772	0.1914	0.9988	0.9942	1.0690	27.8019	0.3460	0.8769	9.8046	1.2443	363.4060
	20	-14.8021	46.7446	0.1829	0.9993	0.6743	0.9372	21.8606	0.3425	0.8478	9.6957	1.1084	279.3489
	30	-10.6889	39.2327	0.2031	0.9976	1.2519	0.8928	18.8932	0.3552	0.8635	9.0704	1.0622	246.8830
	40	-10.6521	34. 9745	0.1988	0.9974	1.1310	0.7672	15.6207	0.3171	0.8550	8.0695	0.9184	259.6366
	50	-12.0452	33.0132	0.1834	0.9976	0.9077	0.6478	13.1503	0.2711	0.8368	7.1572	0.7802	197.5803
G S F Egypt	0	-1.0882	24.7077	0.2892	0.9987	1.0109	0.9250	14.8821	0.4383	0.9016	8.6858	1.0979	-41.3662
	10	-1.8552	27.2569	0.2502	0.9977	1.1861	0.8442	17.5942	0.3310	0.9028	7.4574	0.9896	146.1422
	20	-12.1265	35.3254	0.1851	0.9967	1.1510	0.7072	14.9916	0.2844	0.8499	7.4824	0.8473	53.2270
	30	-17.3870	40.1694	0.1555	0.9987	0.6468	0.6482	14.9393	0.2439	0.8212	7.1874	0.7751	56.2347
	40	-14.3392	32.3950	0.1605	0.9996	0.2818	0.5350	11.2610	0.2187	0.8006	6.3321	0.6452	67.8882
	50	-16.4422	34.9791	0.1544	0.9998	0.2119	0.5478	11.3550	0.2279	0.7851	6.7013	0.6632	69.6273

Table(5.18) Effect of 6-month storage at 30 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

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	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Lidl	0	-2.7603	32.4756	0.2501	0.9983	1.2147	0.9998	20.4163	0.3991	0.8989	9.0224	1.1742	-7.0309
	10	-6.2628	35.3795	0.2240	0.9988	0.9201	0.9299	19.9277	0.3605	0.8801	8.9079	1.0958	-47.5424
	20	-8.9196	33.3554	0.2128	0.9989	0.7714	0.7995	15.6297	0.3393	0.8562	8.4507	0.9562	-12.4805
	30	-8.2502	29.7850	0.2126	0.9992	0.5841	0.7104	13.5750	0.3074	0.8500	7.6759	0.8517	25.6895
	40	-5.0511	25.0991	0.2333	0.9998	0.2736	0.6844	12.8618	0.2962	0.8599	7.2082	0.8152	133.7332
	50	-3.3686	21.0602	0.2511	0.9998	0.2450	0.6357	11.2165	0.2861	0.8613	6.7484	0.7565	177.3152
Kraft	0	-2.3848	27.3009	0.2585	0.9986	0.9485	0.8739	16.6528	0.3688	0.8961	8.1095	1.0310	-115.6691
	10	-6.8833	29.4976	0.2283	0.9988	0.7940	0.7753	14.2035	0.3444	0.8633	8.1410	0.9288	39.4313
	20	-6.8257	25.9723	0.2241	0.9988	0.6811	0.6607	11.7083	0.3023	0.8543	7.1728	0.7956	-96.4177
	30	-5.1561	20.8581	0.2280	0.9990	0.5026	0.5445	9.6402	0.2487	0.8562	5.8782	0.6548	-57.4613
	40	-3.0786	18.7543	0.2454	0.9998	0.2330	0.5498	10.0607	0.2416	0.8683	5.6773	0.6540	21.7184
	50	-1.2182	15.3567	0.2733	0.9999	0.1535	0.5284	9.0952	0.2394	0.8810	5.2915	0.6255	145.0700
Werder	0	3.9215	15.4975	0.3753	0.9999	0.3160	0.9119	12.6868	0.4511	0.9317	7.4506	1.0564	1.0231
	10	3.1744	14.7493	0.3554	0.9999	0.0780	0.7896	11.9331	0.3738	0.9264	6.5786	0.9155	-209.4090
	20	8.1327	11.7998	0.3830	0.9999	0.0731	0.7698	15.4144	0.2854	0.9592	4.6196	0.8590	-127.3629
	30	7.6990	10.1833	0.3876	0.9999	0.0576	0.6839	13.9750	0.2482	0.9614	3.9778	0.7604	-72.7399
	40	4.2503	10.9964	0.3593	0.9999	0.0963	0.6177	11.0303	0.2569	0.9430	4.4430	0.7039	-40.5973
	50	6.2757	7.2531	0.4053	0.9999	0.1123	0.5317	10.6003	0.1948	0.9650	2.9722	0.5882	1.2789
Heinz	0	1.8216	27.4815	0.2686	0.9988	0.9440	0.965	21.3540	0.3527	0.9172	7.8121	1.1151	294.9590
	10	-7.7440	30.5158	0.2146	0.9977	1.0407	0.7424	14.6754	0.3121	0.8660	7.6119	0.8869	78.6101
	20	-0.3756	27.8413	0.2267	0.9989	0.6982	0.7871	21.0951	0.2407	0.9074	6.3160	0.9023	156.8945
	30	-15.0661	36.6743	0.1763	0.9993	0.5111	0.6753	13.0414	0.2958	0.8088	8.0247	0.8190	93.4156
	40	-11.5607	30.0806	0.1870	0.9995	0.4009	0.5961	11.0441	0.2684	0.8127	7.0853	0.7232	162.5780
	50	5.5125	13.6903	0.2850	0.9998	0.2107	0.5638	15.6874	0.1585	0.9401	3.6664	0.6307	208.8800

Table(5.18) Continue: Effect of 6-month storage at 30 °C on rheological properties of tomato ketchups (Herschel-Bulkley and Casson parameters)

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	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Reichelt	0	7.8362	29.4379	0.2419	0.9985	0.9534	0.9752	31.1593	0.2359	0.9349	6.2547	1.0897	22.6384
	10	-0.1810	33.1148	0.2138	0.9994	0.5455	0.8846	26.1997	0.2412	0.9067	6.8736	1.0060	80.1464
	20	-3.1791	31.7463	0.2042	0.9999	0.2065	0.7812	22.0894	0.2269	0.8889	6.6577	0.8955	-41.7320
	30	-3.5920	26.0179	0.2152	0.9999	0.1077	0.6650	16.3938	0.2245	0.8743	6.2454	0.7721	-23.0860
	40	-2.2333	20.7313	0.2344	0.9997	0.2731	0.5878	13.1155	0.2169	0.8712	5.7313	0.6854	-20.2277
	50	-1.6598	17.5584	0.2488	0.9994	0.3700	0.5356	10.9274	0.2131	0.8675	5.4027	0.6276	114.9808
Americana Egypt	0	3.4049	16.2439	0.4442	0.9994	1.0882	1.2903	10.4392	0.8267	0.9458	10.2421	1.5186	-52.2962
	10	2.6095	15.4191	0.4119	0.9995	0.8335	1.0538	10.0122	0.6380	0.9372	8.7820	1.2436	50.0933
	20	1.8725	10.7720	0.4166	0.9995	0.5680	0.7524	6.9680	0.4601	0.9379	6.2584	0.8879	-133.0647
	30	1.4662	10.2855	0.3936	0.9996	0.4359	0.6448	6.6756	0.3775	0.9309	5.5465	0.7617	35.3953
	40	1.1915	8.4105	0.3974	0.9997	0.3272	0.5363	5.3964	0.3181	0.9303	4.6463	0.6341	-5.0845
	50	0.6763	8.2046	0.3746	0.9997	0.2766	0.4673	4.9947	0.2722	0.9201	4.2675	0.5553	24.7189
Heinz Egypt	0	6.9939	30.4044	0.2815	0.9972	1.7766	1.1815	28.9425	0.3864	0.9392	8.1153	1.3447	464.3567
	10	-0.6553	31.4853	0.2477	0.9984	1.0973	0.9786	22.4498	0.3498	0.9077	8.2303	1.1348	194.3901
	20	-4.9995	30.3887	0.2307	0.9983	0.9972	0.8293	17.2095	0.3299	0.8821	7.9538	0.9785	219.6068
	30	-4.4847	26.5996	0.2374	0.9957	1.4488	0.7489	14.4978	0.3166	0.8889	7.1461	0.8901	150.6879
	40	-5.6766	24.4609	0.2257	0.9962	1.1447	0.6349	11.8683	0.2786	0.8736	6.4464	0.7610	211.6518
	50	-7.5117	24.2036	0.2069	0.9967	0.9311	0.5525	10.1838	0.2479	0.8507	6.0240	0.6675	297.9557
G S F Egypt	0	-1.4861	23.9061	0.2819	0.9985	1.0176	0.8607	14.1815	0.4025	0.8995	8.1198	1.0221	-70.9160
	10	-5.7271	30.6702	0.2301	0.9970	1.3120	0.8277	16.4258	0.3436	0.8830	8.0137	0.9830	72.6882
	20	-9.1568	33.6476	0.1948	0.9970	1.1213	0.7336	16.7326	0.2732	0.8694	7.1860	0.8681	61.1370
	30	-16.0020	39.1541	0.1611	0.9985	0.6980	0.6622	15.3195	0.2476	0.8294	7.2016	0.7903	34.9267
	40	-18.0370	38.0925	0.1532	0.9995	0.3634	0.5910	12.2811	0.2455	0.7902	7.1581	0.7156	91.8619
	50	-16.5575	34.1140	0.1561	0.9999	0.1669	0.5345	10.2078	0.2386	0.7681	6.8542	0.6528	91.6479

5.3.6. Effect of storage duration and temperature on effective viscosity (η_{eff}) of tomato ketchups:

The storage duration and temperature showed higher significant effect on effective viscosity (η_{effHB} and η_{effCA}) for tomato ketchups. During storage for 6-month at 5, 20 and 30 °C there was a drop in the (η_{effHB} and η_{effCA}) of all tomato ketchups (Figs., 5.16-18 and Tables (5.10-18)). ANOVA showed effective viscosity to be highly significant in discriminating among tomato ketchups samples during stored ($P < 0.01$). A highest drop in (η_{effHB} and η_{effCA}) was observed in tomato ketchups storage at temperature 30 °C, followd by tomato ketchup stored at 20 °C, while storage of tomato ketchups for 6-month at 30 °C resulted into greater decrease in the (η_{effHB} and η_{effCA}) Fig., 5.9. It showed that the η_{effHB} for Werder, Reichelt and Americana, respectively. tomato ketchup stored for 2, 4 and 6 months at storage temperature 5, 20 and 30 °C.

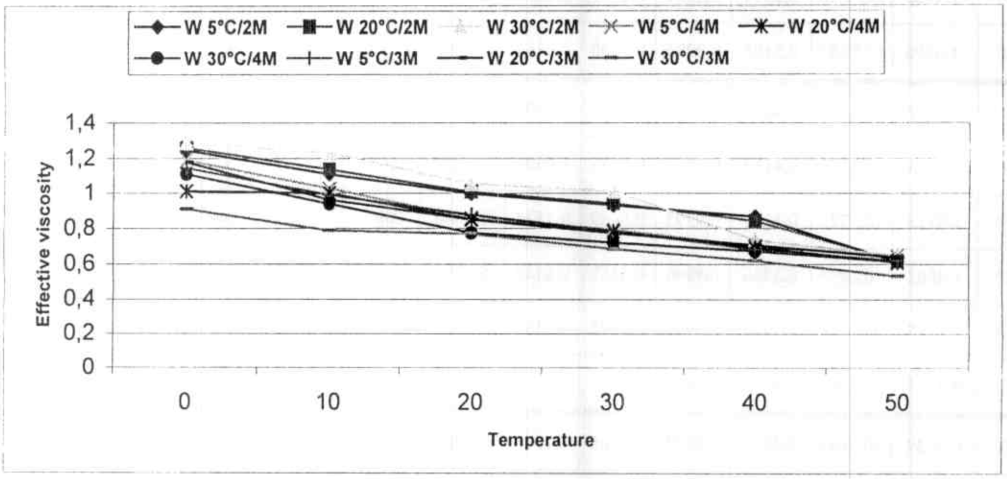


Fig., 5.16 Effect of storage at different temperatures and different times on effective viscosity of Werder (W), tomato ketchup.

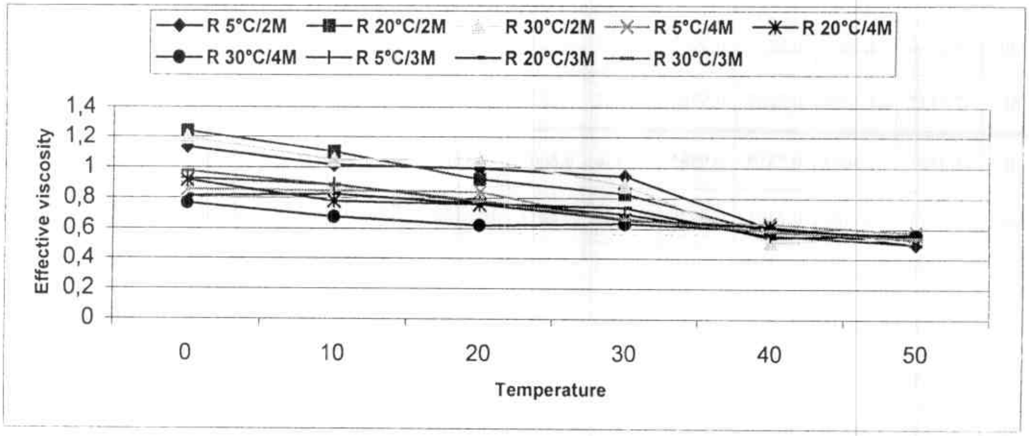


Fig., 5.17 Effect of storage at different temperatures and different times on effective viscosity of Reichelt(R), tomato ketchup.

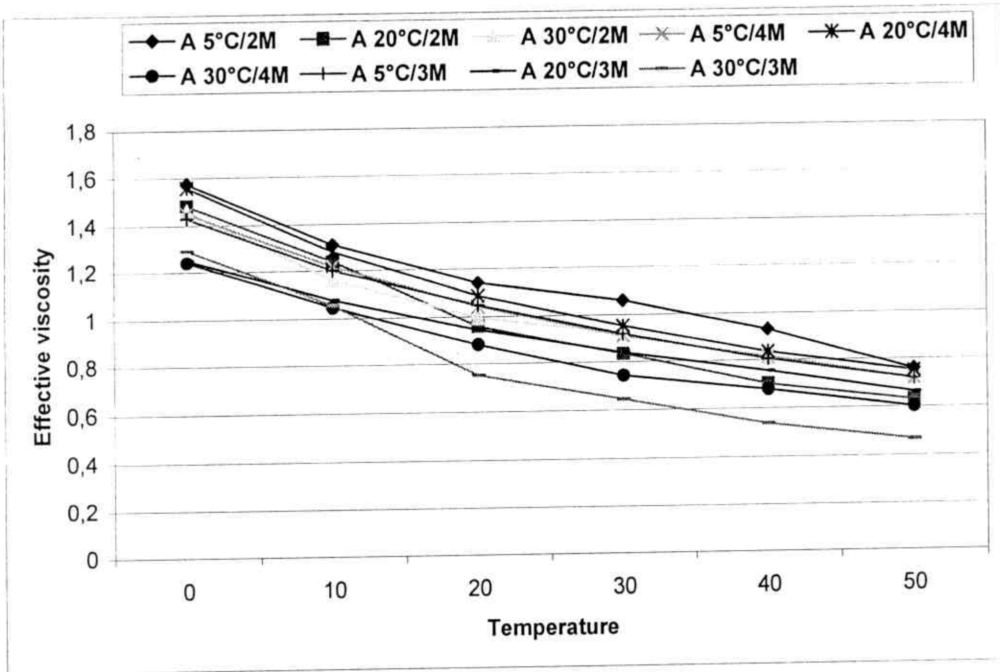


Fig., 5.18 Effect of storage at different temperatures and different times on effective viscosity of Americana(A) tomato ketchup.

5.3.7.Effect of storage for 6-month on rheological behavior of tomato ketchup:

Design of equipment for fluid flow and heat transfer operations involved in the manufacture of tomato ketchup require data on the rheological properties of this product. During storage tomato ketchup tends to loose its consistency (viscosity) due to hydrolysis and also there is some syneresis (serum loss), both of which are not liked by the consumer.

The obtained data from the analysis of variance showed that the changes occurred during 6-month storage for the different tomato ketchup blends in Herschel-Bulkley and Casson models parameters were highly significant, ($P<0.01$). The F values were more than one between different blends, different storage periods, different storage temperatures, and measurement temperature and at the same time for the interaction . This means that the different blends were influenced by storage time and the time of storage affect in the different blends.

After 6-month storage at 5°C, 20 °C and 30 °C Herschel-Bulkley model and Casson model parameters were significantly affected by storage temperature and storage time (Tables 5.16-18) for 6-month storage resulted in significant decreases ($p < 0.05$) in the K for tomato ketchups stored at 5, 20 and 30 °C indicating that during this time interactions between particles are stronger. We found also storage time produced significant decrease in n for ketchup stored at 5, 20 and 30 °C; it was 0.32 before storage, dropped to 0.259, 0.256 and 0.250

for Lidl tomato ketchup at 0 °C temperature after storage 6-month, respectively. And it was 0.33 before storage, dropped to 0.31, 0.29 and 0.28 for GSF Egypt tomato ketchup at 0 °C temperature after storage 6-month, respectively. The η_{effHB} and η_{effCA} were decreased as storage time and temperature increasing. It is concluded that the rheological model obtained can be used to predict changes that may be take place in tomato products during storage.

During the rest of storage time (6 months) the reduction in the rheological parameters values may be either attributed to damage of pectic substances or a little bit reactivation of pectin methylestrase occurred during the storage. By calculating the thixotropic values, it was clear that it had descending tendency as a result of storage.

5.3.8.Effect of storage at different temperatures and different times on activation energy of tomato ketchup:

At a particular concentration, viscosity decreased with temperature. This effect of temperature on the flow behavior of tomato ketchup described by Arrhenius relationship. The Arrhenius constants for all temperatures range 0 –50 °C (Ea and η_∞) together with regression coefficients are listed in Table (5.19). The flow activation energy decreased with increasing the storage temperature for all tomato ketchup. The highest decreased in (Ea) was observed in all tomato ketchup samples storage at temperature 30 °C, followed by tomato ketchup samples storage at 20 °C. Stored of tomato ketchups for 6-month at 30 °C resulted into greater decrease in the Ea (Table 5.19). The Ea values for Heinz tomato ketchup (10.91, 10.86 and 10.39), (7.73, 7.44 and 7.15) and (7.58, 7.55 and 6.12) at storage temperature (5, 20 and 30 °C) and storage time (2, 4 and 6), respectively. These results were in agreement with **Vitali and Rao (1984) and Crandall *et al.* (1982)**. On the other hand the η_∞ values was increased with increasing the storage temperature. It was (2.90, 2.99 and 3.34 mPa.s) for Lidl tomato ketchup after storage 2-month at storage temperature (5, 20 and 30 °C), respectively. And it was (2.94, 3.20 and 3.49 mPa.s) for GSF Egypt tomato ketchup after storage 6-month at storage temperature (5, 20 and 30 °C), respectively.

The regression analysis showed that the Arrhenius equation is applicable for all samples ($R^2 \geq 0.91$).

5.3.9.Effect of storage at different temperatures and different times on oscillation tests of tomato ketchups:

For storage temperature and time and their effects on the oscillation tests during storage, linear regressions of ln ω vs ln G′ and ln G′′ data were estimated. Tables A5.19-22 show the effect of storage time and temperature on the slopes (x′ and y′′) and ln of intercepts ($\ln K_1'$ and $\ln K_2''$) of ln ω vs ln G′ and ln G′′ regressions for all tomato ketchups during storage. The correlation coefficients of regressions showed that more than 0.99. G′ values were higher than the G′′ in all cases. Because tomato ketchup samples have positive slopes and G′ is higher than G′′ at all values of ω, tomato ketchup samples had shear-

Table(5.21) Arrhenius-type constants relating the effect of temperature and viscosity at 100 RPM on tomato ketchup stored for 2,4 and 6 Months at Different Storage Temperatures

Products	Storage Temperature	Storage time									Temperature range (°C)
		2 months			4 months			6 months			
		Ea (kJ/mol)	η_∞ (mPa.s)	R^2	Ea (kJ/mol)	η_∞ (mPa.s)	R^2	Ea (kJ/mol)	η_∞ (mPa.s)	R^2	
Lidl	5°C	9.2684	2.9011	0.9879	9.2959	2.9204	0.9833	7.8200	3.3824	0.9899	0 - 50
	20°C	9.1188	2.9947	0.9275	8.5119	3.2372	0.9950	7.2138	3.7540	0.9910	0 - 50
	30°C	8.2010	3.3443	0.9587	8.3215	3.2843	0.9976	6.6806	3.9785	0.9768	0 - 50
Kraft	5°C	13.110	1.2176	0.9348	9.2551	2.7546	0.9933	8.2078	3.1548	0.9680	0 - 50
	20°C	12.413	1.4401	0.9797	8.9666	2.8624	0.9700	7.8690	3.3061	0.9608	0 - 50
	30°C	10.931	2.0662	0.9721	7.4299	3.3856	0.9683	7.6480	3.4445	0.9779	0 - 50
Werder	5°C	10.571	2.5896	0.9345	9.0115	3.0987	0.9965	8.9866	3.0863	0.9986	0 - 50
	20°C	9.300	3.0849	0.9497	8.4271	3.2579	0.9781	8.5376	3.268	0.9936	0 - 50
	30°C	8.918	3.2348	0.9518	7.7329	3.5681	0.9872	7.4760	3.5324	0.9829	0 - 50
Heinz	5°C	10.910	2.0797	0.9691	7.7255	3.4861	0.9882	7.5811	3.5102	0.9533	0 - 50
	20°C	10.855	2.1493	0.9837	7.4435	3.5928	0.9897	7.5490	3.5426	0.9674	0 - 50
	30°C	10.392	2.2831	0.9802	7.1473	3.7679	0.9979	6.1213	4.1542	0.9601	0 - 50
Reichelt	5°C	13.272	1.3524	0.9103	11.7171	2.2700	0.9334	9.8870	2.5605	0.9767	0 - 50
	20°C	13.048	1.4447	0.9791	10.8353	2.3775	0.9871	9.8509	2.5781	0.9884	0 - 50
	30°C	12.071	1.8380	0.9122	9.5887	2.6042	0.9639	9.5935	2.6989	0.9961	0 - 50
Americana Egypt	5°C	10.092	2.9246	0.9917	10.958	2.3599	0.9990	10.106	2.8176	0.9996	0 - 50
	20°C	10.089	2.8541	0.9982	10.819	2.5821	0.9980	10.378	2.9723	0.9994	0 - 50
	30°C	10.066	2.8248	0.9917	10.783	2.3779	0.9980	9.1097	3.1157	0.9945	0 - 50
Heinz Egypt	5°C	10.520	2.4766	0.9620	9.755	2.9407	0.9895	9.4464	3.0102	0.9879	0 - 50
	20°C	8.1656	3.4288	0.9691	7.5928	3.7213	0.9517	8.8430	3.3126	0.9925	0 - 50
	30°C	7.5238	3.5546	0.9858	7.2305	3.7818	0.9619	7.0250	3.7877	0.9970	0 - 50
G S F Egypt	5°C	10.111	2.5532	0.9947	9.5079	2.7128	0.9912	9.1198	2.9417	0.9590	0 - 50
	20°C	10.077	2.5505	0.9978	9.8288	2.9405	0.9896	8.3087	3.2002	0.9949	0 - 50
	30°C	9.5578	2.7306	0.9981	7.2476	3.4559	0.9830	7.5701	3.4938	0.9858	0 - 50

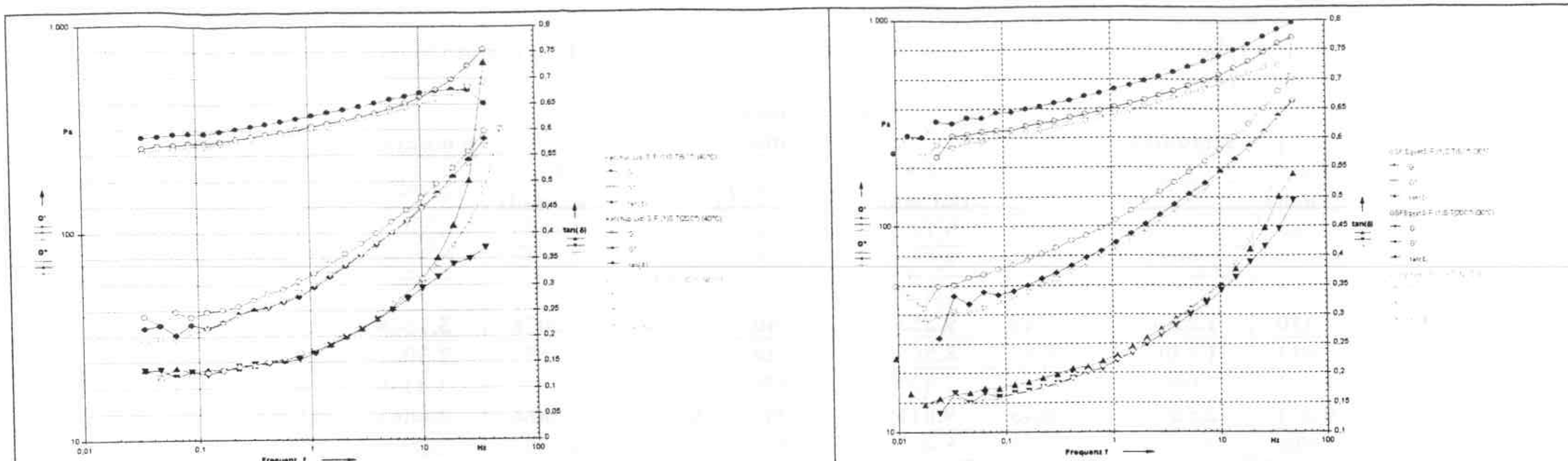


Fig. 5.19 Frequency dependence of the Storage (G′) and loss (G′′) modulus of the storage time and temperature for tomato ketchups (Lidl and GSF Egypt).

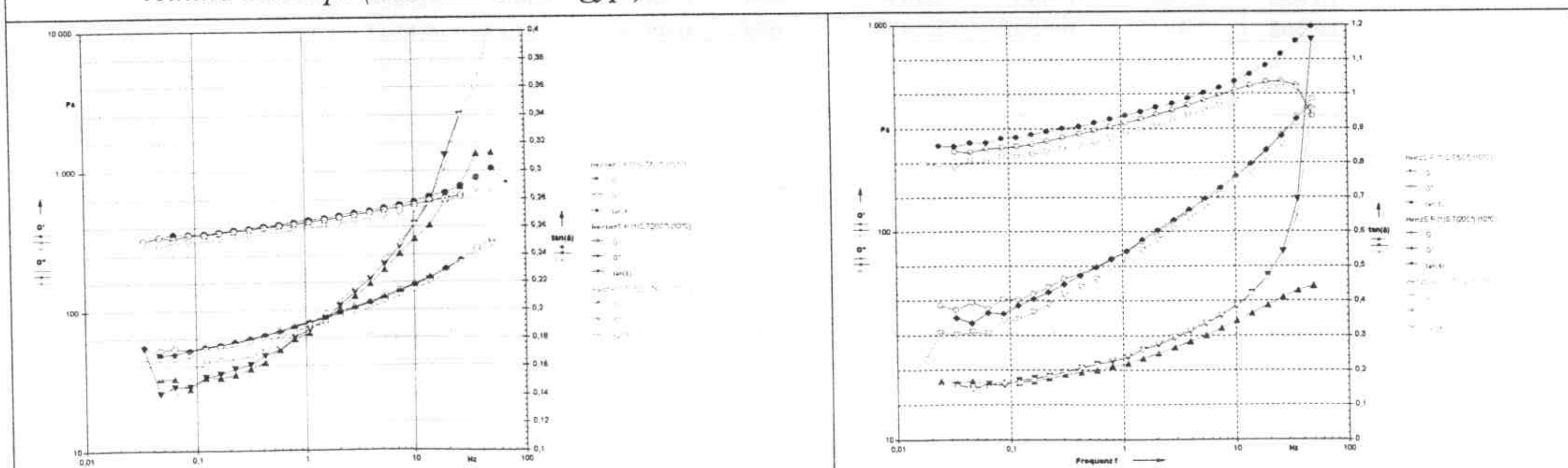


Fig. 5.20 Frequency dependence of the Storage (G′) and loss (G′′) modulus of the storage time and temperature for tomato ketchups (Reichelt and Heinz).

thinning behavior during storage, such as that of weak gels or concentrated solutions. In the most cases y′′ values were higher than x′ values. This means that the tomato ketchups during storage did not behave as true gels, but exhibited weak gel properties. x′ and y′′ decreased significantly with sample temperature(**Alvarez *et al.*,2004**) and **Yoo (2001)**.

5.4.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 (**Tanglertpaibul and Rao,1987**) 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.

5.4.1.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. 5.21-23 the shape of the curve indicates pesudoplasticity, and yield point. Also in Figs. 5.21-23 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 (5.23).

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 5.23 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 (5-12) described the correlations between τ_0 and pulp content.

$$\tau_{0HB} = (0.6361 * \text{pulp content}) - 5.3841 \qquad (5\text{-}12)$$

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 the yield stress correlated with pectin content and pulp content.

Table(5.23) 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

Flow behavior index:

The values for flow behavior index n were always lower than 1 which indicates the plastic 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 5.3). It increased from 0.94 Pa.s^n 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 (5.23). 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 tomato puree and tomato paste. Because the different in pulp content (see Table 5.3) and may be depended on Particle size **(Yoo and Rao 1994); Noomhorm and Tansakul (1992)**

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.

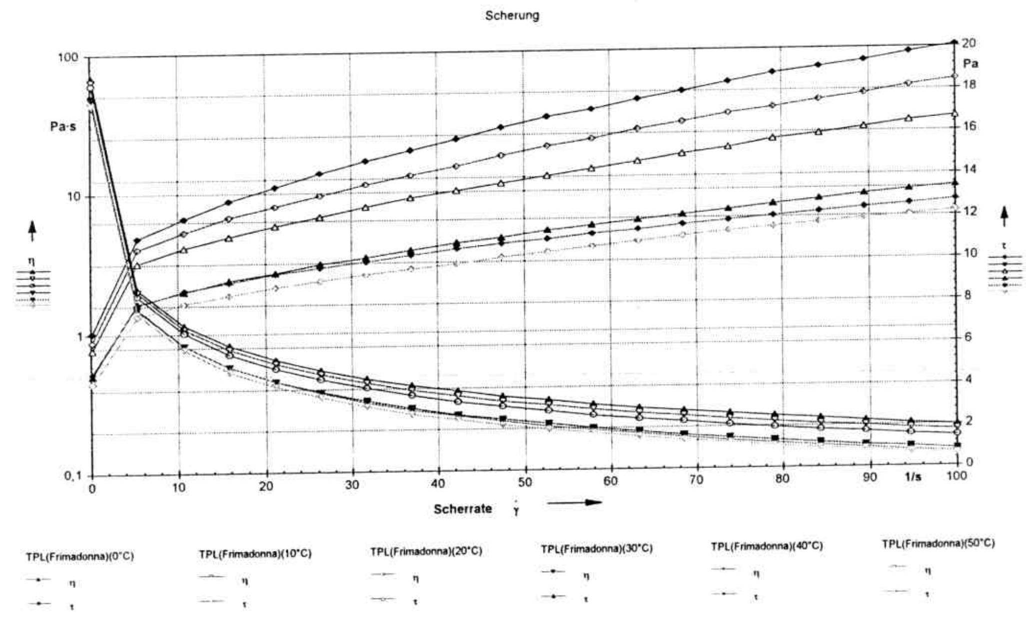


Fig.5.21 The flow and viscosity curves for the tomato puree at all investigated temperatures

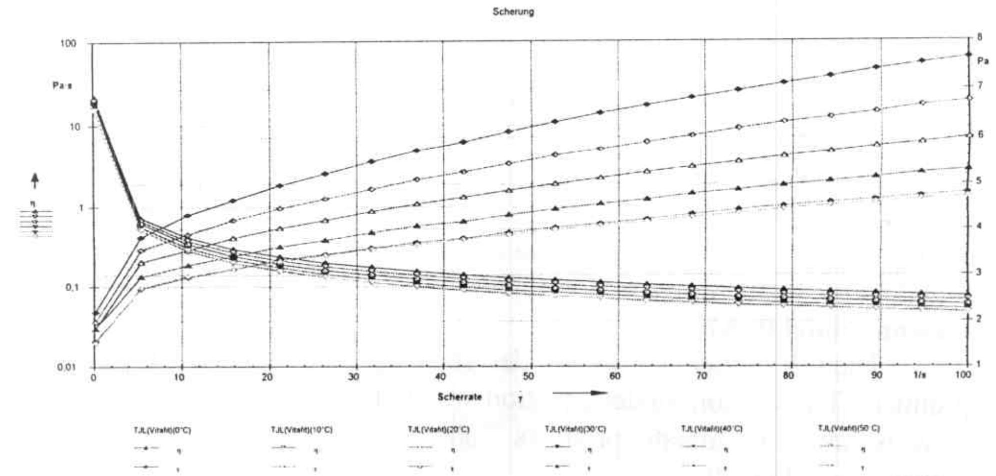


Fig.5.22 The flow and viscosity curves for the tomato juice at all investigated temperatures

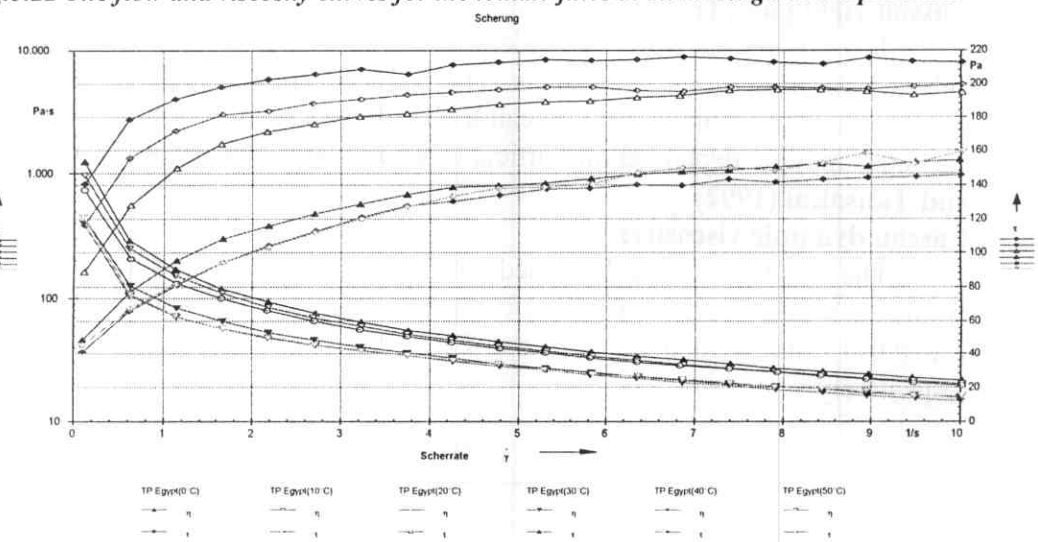


Fig.5.23 The flow and viscosity curves for the tomato paste at all investigated temperatures

5.4.2. 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).**

5.4.2.1 Amplitude sweep:

Typical amplitude sweep profiles for three tomato products are shown in Figs.5.24-26. 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.

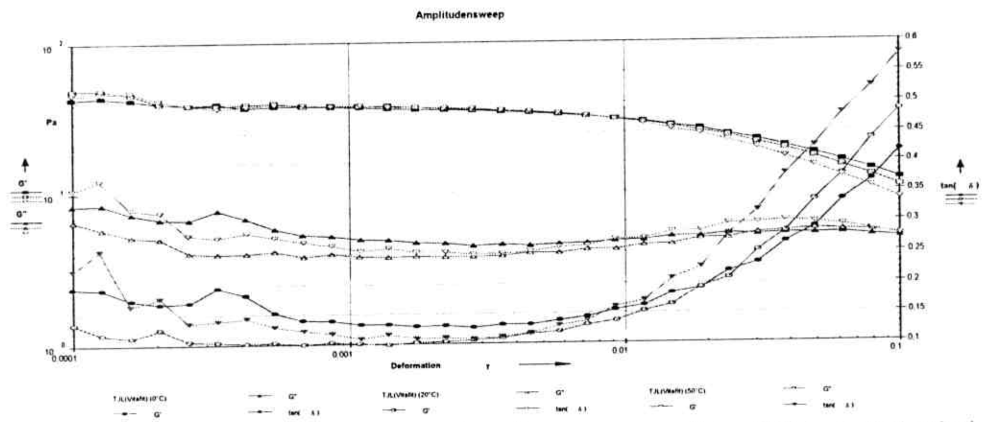


Fig.5.24: Amplitude sweeps of tomato juice. The storage modulus G′(elastic behavior) and loss modulus G′′(viscous behavior) curves are shown as a function of the deformation

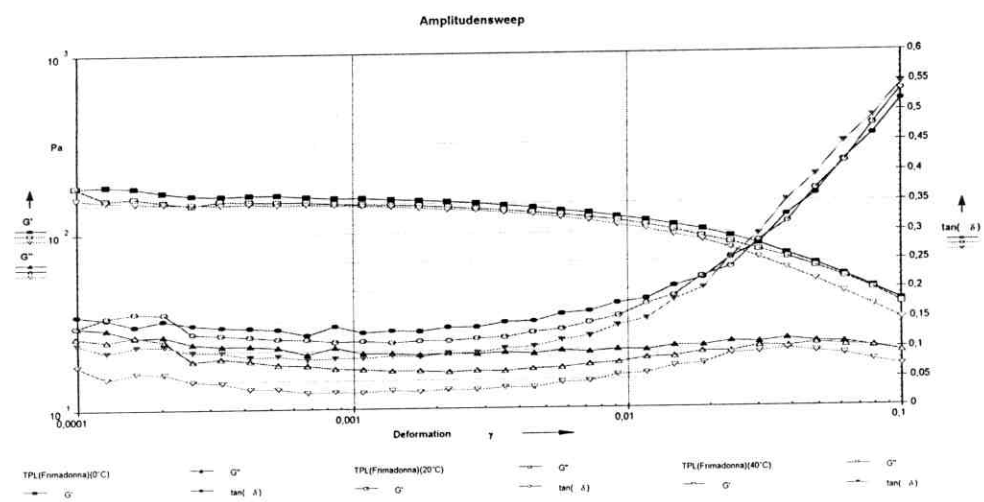


Fig.5.25: Amplitude sweeps of tomato puree. The storage modulus G′(elastic behavior) and loss modulus G′′(viscous behavior), curves are shown as a function of the deformation.

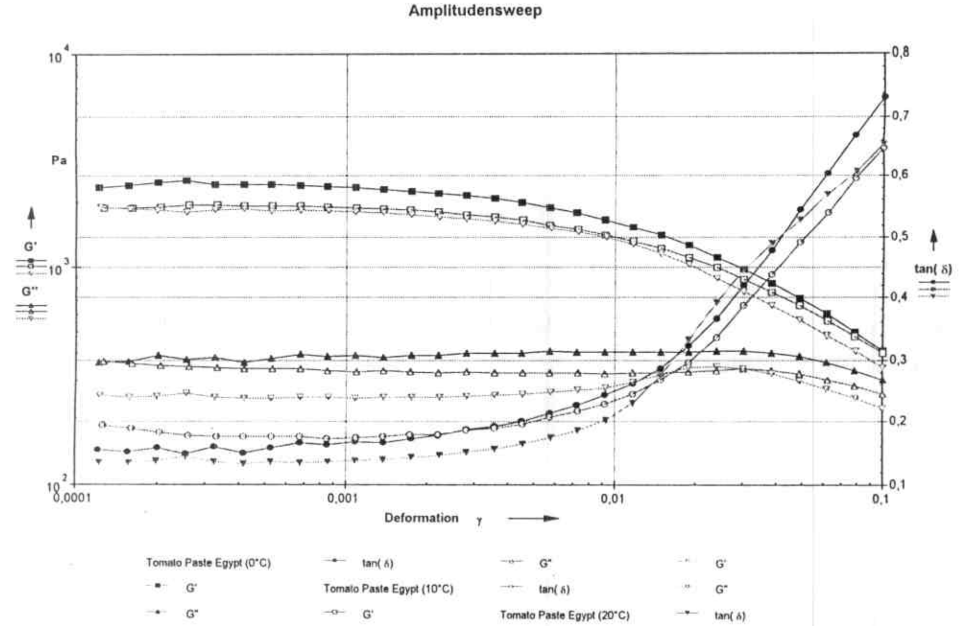


Fig.5.26: Amplitude sweeps of tomato products samples the storage modulus G′(elastic behavior) and loss modulus G′′(viscous behavior) curves are shown as a function of the deformation

5.4.2.2 Frequency sweep:

Magnitudes of G′ and G′′ as a function of frequency (f) at assay temperature are illusterated in Figs. 5.27-29, 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 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 5.24 contains magnitudes of the slopes (x′ and y′′) and intercepts (K_1′ and K_2′′) 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 ($K_1$\` and K_2\`\`) 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**)

Table (5.24) Dynamic shear data of tomato juice, puree and paste [Slopes and intercepts of (G′, G′′) versus (frequency, rad S^{-1})]

Product	Temp.	G′			G′′		
	°C	Constant (K_1')	Constant (x′)	R^2	Constant (K_2'')	Constant (y′′)	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
Lidl 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

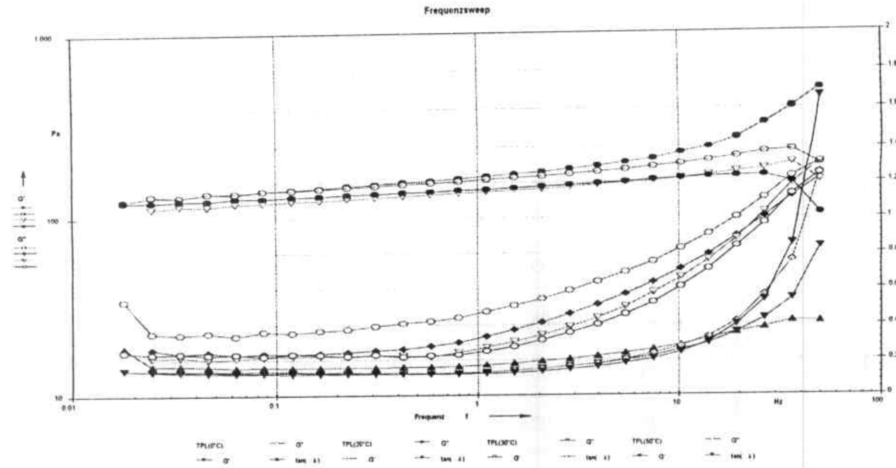


Fig. 5.27: Frequency sweeps of tomato puree. The storage modulus G′ and loss modulus G′′ curves are shown as a function of the angular frequency

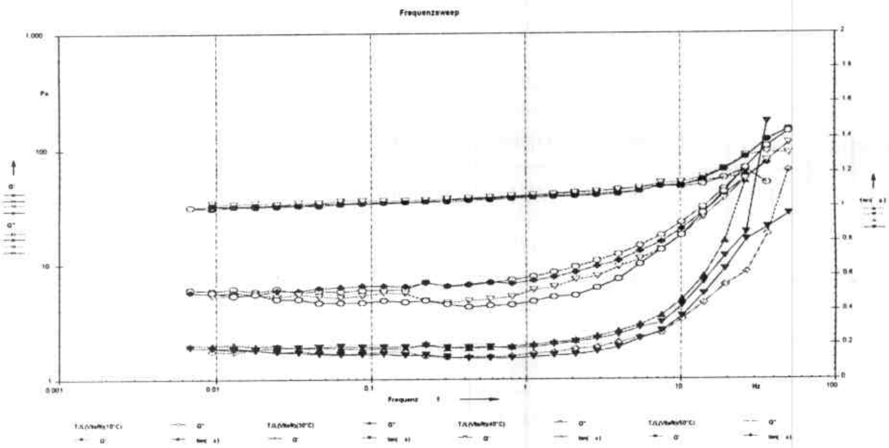


Fig. 5.28: Frequency sweeps of tomato juice. The storage modulus G′ and loss modulus G′′ curves are shown as a function of the angular frequency

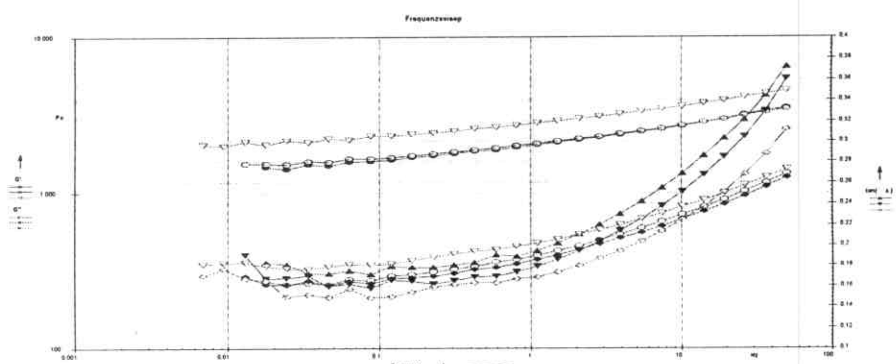


Fig. 5.29: Frequency sweeps of tomato paste. The storage modulus G′ and loss modulus G′′ curves are shown as a function of the angular frequency

5.4.2.3 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 $\delta = \text{arctg}\ G''/G'$ or $\delta = \text{arctg}\ \eta'/\eta''$ 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 (5.25): 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

5.4.3.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 (5.26). 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,b)**, who reported that Ea increases with sugar content and decreases with pulp content. It can be seen in Table 5.3. 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 (5.26) 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

5.5.Mechanical properties of tomato fruit:

Texture is an important quality attribute of foodstuffs. When a food is processed, its structure and its composition may be altered and, therefore, the texture and the other sensory properties undergo changes which affect the acceptance of the product.

The results of instrumental tests are summarised in Table 5.27 the values are means of 10 replicates for compression test, 10 for penetration test.

5.5.1.Effect of storage and ripening at different temperatures on mechanical properties of tomato fruit:

Softening during storage, distribution and ripening of tomatoes can be a major problem because it may be an increase to their susceptibility to damage. The fruit texture has been used as an indication of fruit quality (**Burton 1982**), and texture may be the final index by which the consumers decide to purchase a given batch of tomatoes (**Gormley and Egan, 1978**).

Compression test for tomato fruits during storage and ripening at different temperatures:

The Mature-green tomato fruits were surface-sterilized by immersion in a 0.1 % (w/v) solution of NaOCl for 3 min, rinsed thoroughly with deionized water and dried. The texture characteristics were tested by using an Instron Universal Testing Machine, model 4301, for flat- plate compression tests, whole tomato fruit were placed on a stationary steel plate and aligned from stem end to stylar end, with the stylar end down. A 5- kN load cell was used in conjunction with a 17.8 * 11.7-cm upper steel plate to compress tomatoes at a deformation speed of 5 $mm.min^{-1}$. The maximum force (N), elastic modulus (MPa), energy or the area between the loading curve and the deformation axis represents the total work of loading (J) and energy at maximum force energy1 or the work required to compress a fruit to maximum force (J) were tabulated in Tables 5.27-28.

Significant differences in mechanical parameters values were observed for storage and ripening conditions of tomatoes. As shown in Figs 5.30-32, the elastic module values and other mechanical parameters as a function of chilling and ripening/storage time were illustrated. The comparisons parameters for tomato fruits tested all two days, all parameters decrease with ripening and storage time. The significant decrease in elastic module of C (chilled), PC (prechilled) and NC (nonchilled) tomatoes with ripening is consistent with a concomitant loss of cell turgor, as has been reported to occur by **Shackel *et al.* (1991)**. During ripening of NC and PC pericarp tissues, increased fluidity occurred at the expense of elasticity, consistent with a progressive reduction in the molecular weight-size distribution of structural macromolecules and specifically, of cell wall polyuronides and hemicelluloses (**Mitcham *et al.* 1989; Jackman and Stanley 1992b ;1995**). Chilling stress was suggested to induce some structural alteration of the middle lamellae of cells or to predispose pectic substances to enhanced breakdown during subsequent ambient temperature ripening. Mechanical parameters values of tomatoes fruits at different conditions were decreased with increasing storage time according to **Errington *et al.* 1997 and Jackman and Stanley,1995**. Maximum force values (N) and elastic modulus values (MPa) are the more sensitive indicator of the texture changes than the other parameters.

As can be seen, there is some difference between the parameters measured for each storage group. Tables 5.27-28 showed that the mechanical parameters at different time and different storage conditions. The changes in weight, diameter and length for the three tested storage conditions are almost linear with time. The decrease in weight ranged between 109.55 to 95.78 g. the decreasing in the nonchilled tomato higher than prechilled and chilled tomatoes.

The rate of change in the texture parameters for non chilled was generally greater than for perchilled and chilled. The greatest change occurred over 6-10 days, (Figs.5.30-32). The texture parameters were corroborating previous results obtained by compression (**Jackman *et al.*, 1992a,b; Jackman and Stanley 1994,1995**). The viscoelasticity or time-dependent behavior of a material refers to its intrinsic mechanical properties that are intermediate between elastic solids and viscous liquids, and are independent of chemical or enzymatic reactions.

If the maximum force values of tomatoes fruits are above 127.8 N they are suitable for making salad and even for marketing. In this red and ripe stage tomatoes were very fresh and firm, easily marketable. If the maximum force values is above 175.8 N those tomatoes are definitely very firm and easily marketable in the supermarket. When the maximum force values of tomatoes reached to 46.15 N , the tomatoes were overripe. The tomatoes in this stage were very soft and could be used for just cooking or producing of tomato paste, and have very poor market quality. In the same time if the elastic module values of tomatoes reached to 0.071 MPa, they are very difficult to sell in the supermarket and very difficult to slice or to use them for making salads. If the elastic module values of tomatoes are higher than 0.145 MPa, (slightly soft) they could be used for making salads especially if their elastic modulus is above 0.212 MPa (very firm). Such tomatoes are easily marketable at the supermarket, according to **Batu 1995 and 2004**. Fig. 5.33 show some examples of compression curves in the force-deformation, for chilled tomato during storage and repining.

Table 5.27 Physico-Mechanical parameters(Compression test) for tomato fruits stored under different conditions

Treat-ment	Storage time	Data	Weight	Diameter	Length	Maximum Force	E Moduls	Energy	Energy1
	(days)		gm	cm	cm	N	MPa	J	J
Chilled	0	06/03/2003	109.55±1.098	5.93±0.14	5.17±0.09	175.80±1.28	0.2120±0.004	1.469±0.027	0.8502±0.014
	2	08/03/2003	109.72±1.409	5.97±0.28	5.18±0.16	159.60±1.79	0.1846±0.006	1.317±0.028	0.8465±0.017
	4	10/03/2003	108.71±1.805	5.93±0.08	5.14±0.13	146.20±2.40	0.1771±0.007	1.096±0.032	0.8217±0.009
	6	12/03/2003	107.62± 1.136	5.91±0.13	5.17±0.14	142.70±2.53	0.1764±0.005	1.083±0.022	0.7677±0.006
	8	14/03/2003	107.44± 1.428	5.86±0.08	5.14±0.16	136.40±2.25	0.1577±0.003	0.9739±0.016	0.7277±0.006
	10	16/03/2003	107.02± 1.099	5.83±0.23	5.14±0.11	134.10±2.78	0.1505±0.005	0.9043±0.014	0.7027±0.005
	12	18/03/2003	106.72± 1.751	5.72±0.11	5.16±0.11	132.20±1.47	0.1476±0.008	0.9026±0.013	0.6996±0.009
	14	20/03/2003	105.91± 1.888	5.75±0.27	5.12±0.27	127.80±1.55	0.1448±0.009	0.9005±0.011	0.6576±0.006
	16	22/03/2003	105.37± 1.007	5.69±0.19	5.09±0.19	119.90±1.36	0.1466±0.007	0.8929±0.009	0.6312±0.007
	18	24/03/2003	104.32± 0.985	5.62±0.10	5.07±0.15	108.10±1.17	0.1212±0.009	0.8637±0.009	0.6206±0.007
	20	26/03/2003	104.84± 0.902	5.65±0.27	5.10±0.12	105.80±1.52	0.1190±0.005	0.8559±0.008	0.6168±0.009
	22	28/03/2003	103.57± 0.879	5.57±0.31	5.06±0.09	101.49±1.40	0.1163±0.004	0.8193±0.009	0.6099±0.008
	24	30/03/2003	103.12± 1.582	5.52±0.12	5.05±0.15	96.78±1.18	0.1145±0.006	0.8073±0.007	0.6047±0.006
	26	01/04/2003	102.86± 1.965	5.49±0.22	5.06±0.10	89.31±1.43	0.1058±0.003	0.7917±0.005	0.5996±0.004
	28	03/04/2003	102.51± 2.021	5.49±0.36	5.03±0.28	83.40±1.02	0.1047±0.007	0.7912±0.008	0.5940±0.007
	30	05/04/2003	102.03± 2.019	5.49±0.37	5.04±0.26	81.20±0.94	0.1029±0.006	0.7925±0.006	0.5947±0.004
Prechilled	14	20/03/2003	105.91± 1.888	5.75±0.27	5.12±0.27	127.80±1.55	0.1448±0.009	0.9005±0.011	0.6576±0.006
	16	22/03/2003	104.74±1.437	5.64±0.19	5.13±0.18	110.90±1.72	0.1331±0.005	0.8867±0.009	0.6445±0.009
	18	24/03/2003	103.89±1.217	5.58±0.22	5.09±0.25	93.44±1.35	0.1200±0.007	0.8067±0.004	0.6023±0.010
	20	26/03/2003	102.50±1.302	5.51±0.29	5.07±0.25	89.40±1.69	0.0973±0.003	0.7506±0.007	0.5686±0.008
	22	28/03/2003	102.11±1.009	5.47±0.16	5.04±0.34	82.02±1.27	0.0926±0.008	0.7234±0.012	0.5344±0.007
	24	30/03/2003	101.89±1.869	5.47±0.25	5.03±0.24	75.04±1.04	0.0888±0.008	0.6903±0.009	0.4770±0.007
	26	01/04/2003	101.44±1.952	5.42±0.24	5.01±0.26	70.61±1.00	0.0859±0.007	0.6791±0.009	0.4761±0.006
	28	03/04/2003	99.509±1.116	5.37±0.25	4.97±0.22	65.24±0.88	0.0827±0.005	0.6669±0.005	0.4186±0.008
	30	05/04/2003	96.079±0.955	5.32±0.31	4.91±0.27	62.69±0.81	0.0791±0.005	0.6629±0.004	0.3902±0.005

Table 5.27 Continue: Physico-Mechanical parameters(Compression test) for tomato fruits stored under different conditions

Treat-ment	Storage time	Data	Weight	Diameter	Length	Maximum Force	E Moduls	Energy	Energy1
	(days)		gm	cm	cm	N	MPa	J	J
Nonchilled	0	06/03/2003	109.55±1.098	5.93±0.14	5.17±0.09	175.767±1.28	0.2121±0.004	1.469±0.037	0.8502±0.024
	2	08/03/2003	108.99±1.448	5.87±0.17	5.18±0.11	157.300±1.74	0.1566±0.005	1.151±0.051	0.7810±0.009
	4	10/03/2003	106.36±1.221	5.75±0.21	5.15±0.14	137.60±2.40	0.1521±0.003	0.9175±0.022	0.7304±0.011
	6	12/03/2003	105.17±0.905	5.61±0.08	5.11±0.18	125.60±3.25	0.1284±0.004	0.7795±0.037	0.6962±0.019
	8	14/03/2003	104.48±0. 811	5.55±0.12	5.082±0.21	116.70±2.78	0.1212±0.009	0.7859±0.026	0.5669±0.022
	10	16/03/2003	103.77±1.805	5.51±0.15	5.056±0.23	104.20±1.84	0.1179±0.008	0.7493±0.011	0.5428±0.018
	12	18/03/2003	101.25±0.762	5.44±0.20	5.03±0.25	102.90±0.85	0.1155±0.008	0.7442±0.016	0.5143±0.012
	14	20/03/2003	100.92±0.721	5.42±0.17	5.00±0.26	98.26±1.96	0.1080±0.006	0.7056±0.019	0.5093±0.014
	16	22/03/2003	99.463±1.116	5.41±0.13	4.96±0.21	88.33±1.08	0.1041±0.009	0.6944±0.014	0.5056±0.015
	18	24/03/2003	100.08±1.699	5.43±0.24	4.87±0.15	86.18±0.92	0.09806±0.005	0.6667±0.008	0.4639±0.010
	20	26/03/2003	98.027±0.894	5.41±0.18	4.89±0.11	71.28±1.09	0.0967±0.003	0.6443±0.009	0.4465±0.009
	22	28/03/2003	97.797±1.008	5.38±0.23	4.82±0.09	62.07±1.35	0.0814±0.004	0.5659±0.007	0.3556±0.012
	24	30/03/2003	96.397±0.573	5.36±0.26	4.75±0.14	59.74±0.89	0.0808±0.005	0.4821±0.008	0.3549±0.011
	26	01/04/2003	96.725±0.499	5.38±0.22	4.75±0.15	51.15±0.82	0.0782±0.002	0.4486±0.009	0.3330±0.008
	28	03/04/2003	96.115±0.861	5.34±0.28	4.59±0.24	49.35±0.87	0.0755±0.006	0.4350±0.011	0.2812±0.012
	30	05/04/2003	95.784±1.353	5.31±0.26	4.63±0.12	46.15±0.81	0.0711±0.003	0.4273±0.009	0.2770±0.011

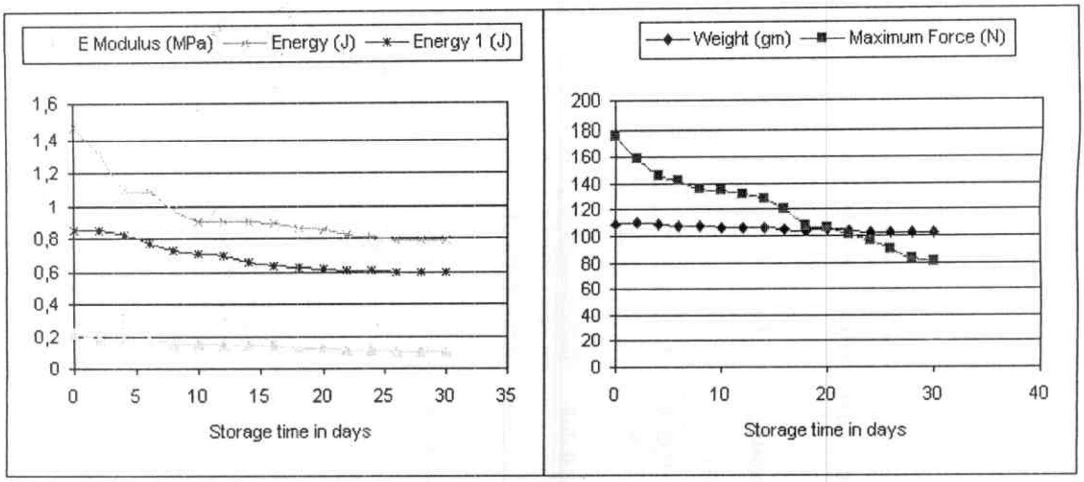


Fig. 5.30: Changes in mechanical properties of chilled tomato during storage and ripening

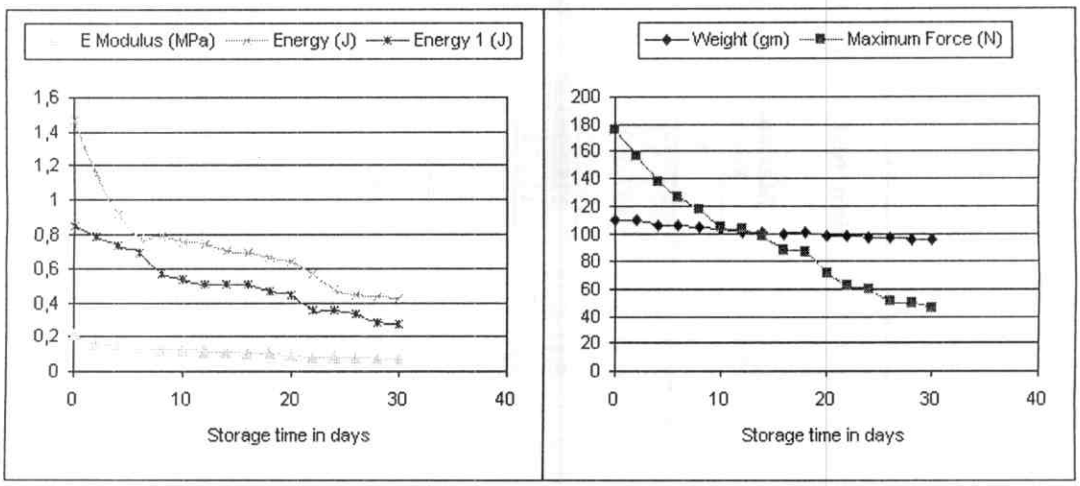


Fig. 5.31: Changes in mechanical properties of Non chilled tomato during storage and ripening

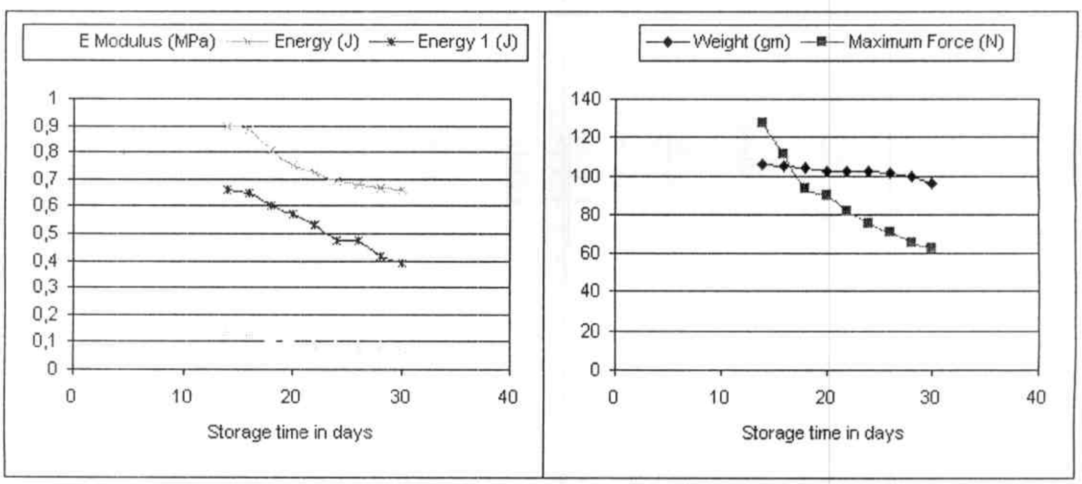
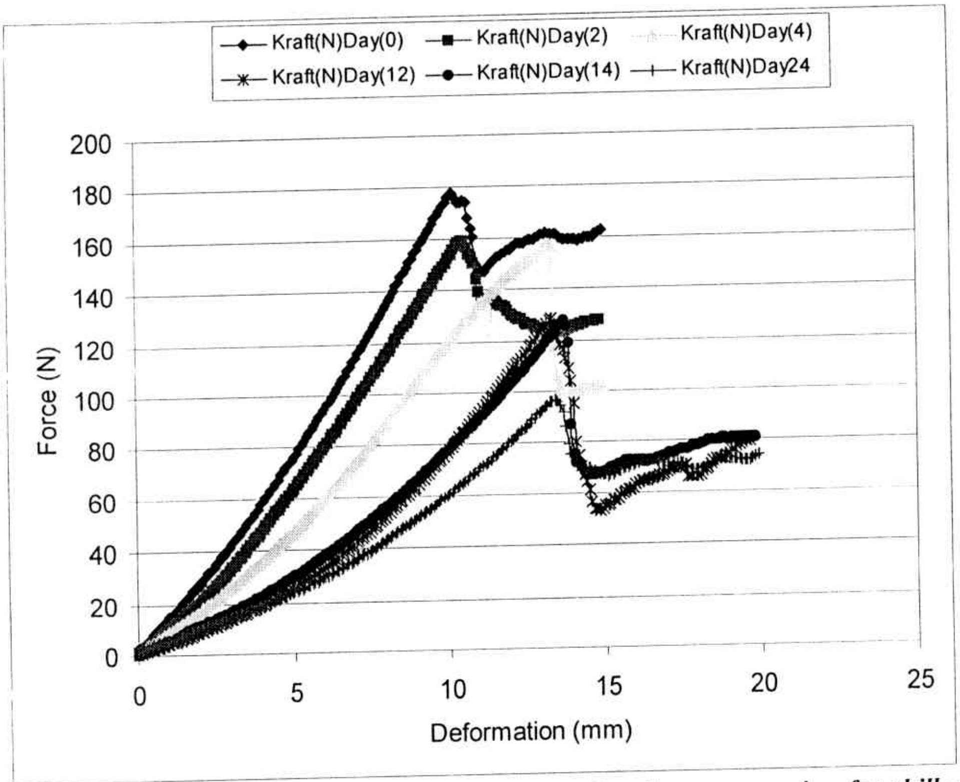


Fig. 5.32: Changes in mechanical properties of Per chilled tomato during storage and ripening



(Fig., 5.33) Typical force- deformation curves for flat-plate compression for chilled tomato during storage and repining

5.5.2.Effect of heat treatment on mechanical properties of tomato fruit:

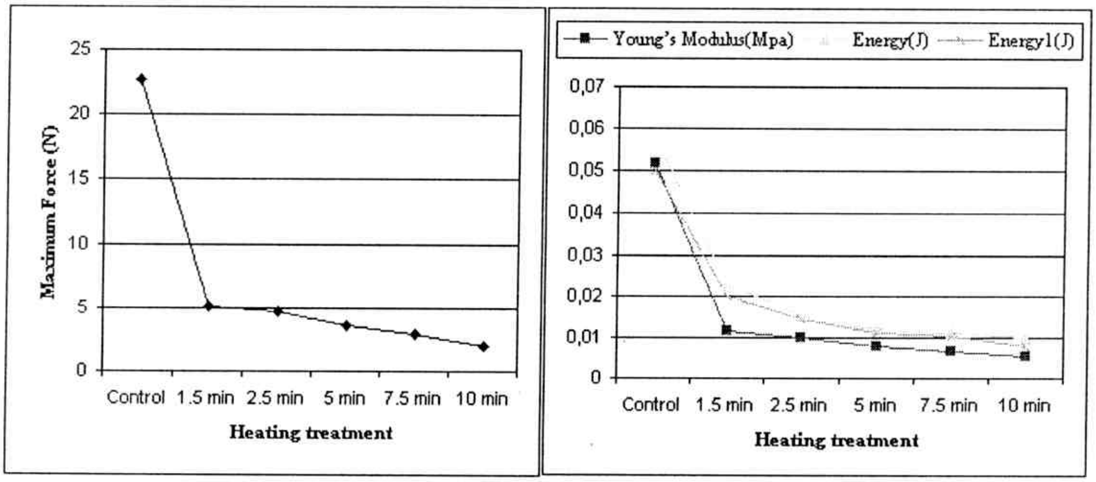
Tomato fruits (*Lycopersicun esculentum*) at the ripe stage were used to study the effect of break temperature 85°C (the best break temperature according to **Ying *et al.*, 1986**) at different times 1.5, 2.5, 5, 7.5 and 10 min. The means and standard errors of the ten replicates of tomato fruits heated at temperature 85 °C and at different time were determined and used in the data analysis Tables 5.28-29 for penetration and Table 5.30 for compression test also all results are showed in Figs. 5.34-36. Heat treated tomato had higher different mechanical parameters values than controls. Maximum force (N) for heat treated tomato were lowest for controls, indicating that these were softest. The same results were observed by **(Abbott *et al.*, 2000)** on heat treated apples. The area under the curve (Energy) and the area under the curve to maximum force (Energy1) were decreased with increasing in heat treatment time.

Table 5.28 Effect of heat treatment on some physico-mechanical parameters tomato fruits (*Lycopersicun esculentum*) by using penetration test 3 mm diameter :

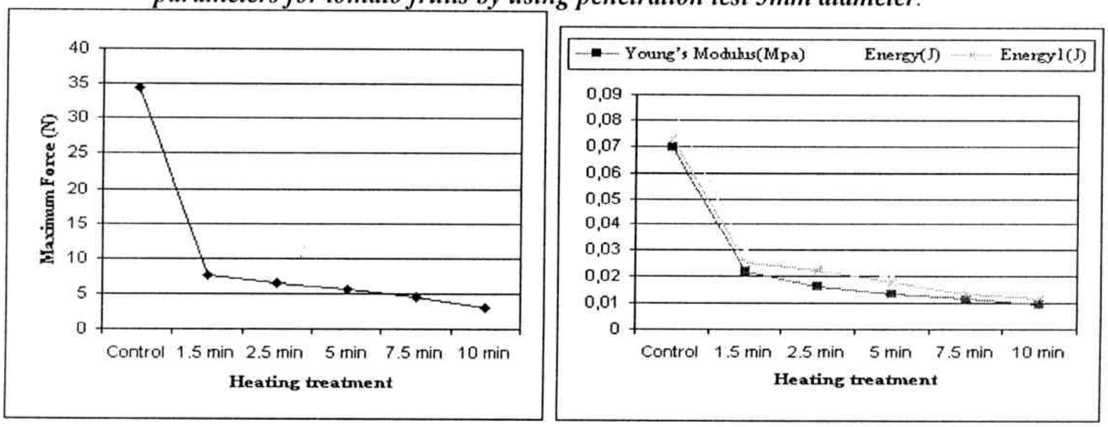
Treatment	Weight	Diameter	Length	Maximum Force	Young's Modulus	Energy	Energy1
	gm	cm	cm	N	MPa	J	J
Control	111.24±1.17	6.05±0.09	5.33±0.17	22.68±0.42	0.0517±0.002	0.0576±0.003	0.0498±0.002
1.5 min	110.85±1.21	6.02±0.11	5.29±0.15	5.17±0.33	0.0116±0.001	0.0231±0.001	0.0199±0.002
2.5 min	111.32±1.44	6.03±0.14	5.35±0.19	4.67±0.19	0.0099±0.003	0.0156±0.002	0.0146±0.001
5 min	110.95±1.16	5.99±0.11	5.31±0.19	3.69±0.44	0.0078±0.001	0.0122±0.001	0.0112±0.003
7.5 min	109.32±1.04	5.97±0.15	5.28±0.17	2.91±0.26	0.0067±0.001	0.0113±0.001	0.0103±0.002
10 min	111.71±1.12	6.11±0.12	5.32±0.18	1.98±0.33	0.0053±0.000	0.0099±0.002	0.0081±0.001

Table 5.29 Effect of heat treatment on some physico-mechanical parameters tomato fruits (*Lycopersicun esculentum*) by using penetration test 5 mm diameter:

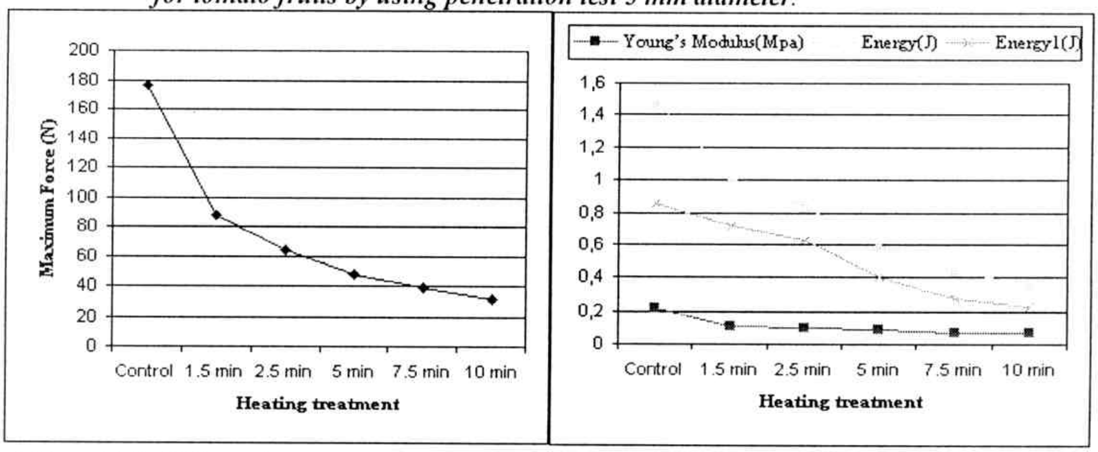
Treatment	Weight	Diameter	Length	Maximum Force	Young's Modulus	Energy	Energy1
	gm	cm	cm	N	MPa	J	J
Control	111.24±1.17	6.05±0.09	5.33±0.17	34.46±0.51	0.0694±0.001	0.0832±0.002	0.0724±0.002
1.5 min	113.12±1.33	6.14±0.31	5.31±0.11	7.54±0.35	0.0219±0.002	0.0295±0.001	0.0252±0.003
2.5 min	112.75±1.15	6.09±0.17	5.32±0.14	6.49±0.34	0.0164±0.002	0.0248±0.001	0.0222±0.002
5 min	113.45±1.09	6.18±0.12	5.35±0.12	5.55±0.27	0.0133±0.001	0.0195±0.002	0.0181±0.001
7.5 min	111.76±1.23	6.07±0.32	5.37±0.15	4.49±0.28	0.0116±0.001	0.0152±0.001	0.0134±0.001
10 min	112.44±1.41	6.11±0.09	5.36±0.11	2.96±0.54	0.0094±0.000	0.0136±0.001	0.0119±0.000



(Fig., 5.34) Effect of heat treatment at 85 °C and different time on some mechanical parameters for tomato fruits by using penetration test 3mm diameter.



(Fig., 5.35) Effect of heat treatment at 85 °C and different time on some mechanical parameters for tomato fruits by using penetration test 5 mm diameter.



(Fig., 5.36) Effect of heat treatment at 85 °C and different time on some mechanical parameters for tomato fruits by using compression test.

Table 5.30 Effect of heat treatment on some physico-mechanical parameters tomato fruits (*Lycopersicun esculentum*) by using compression test:

Treatment	Weight	Diameter	Length	Maximum Force	Young s Modulus	Energy	Energy1
	gm	cm	cm	N	MPa	J	J
Control	109.55±1.10	5.93±0.14	5.17±0.09	175.80±1.28	0.2120±0.004	1.469±0.027	0.8502±0.014
1.5 min	110.65±0.97	5.98±0.26	5.24±0.11	87.71±2.09	0.1078±0.004	1.008±0.029	0.7181±0.017
2.5 min	110.41±1.26	6.06±0.21	5.22±0.14	63.88±1.87	0.1006±0.005	0.8312±0.019	0.6325±0.014
5 min	112.05±0.88	6.12±0.18	5.39±0.12	47.08±1.11	0.0899±0.001	0.6011±0.012	0.4056±0.011
7.5 min	112.11±0.96	6.14±0.34	5.41±0.15	39.24±0.45	0.0721±0.002	0.4436±0.014	0.2704±0.008
10 min	109.89±0.94	6.04±0.31	5.27±0.11	30.95±0.87	0.0665±0.001	0.3529±0.011	0.2271±0.009

Cherry and cherry products

5.6 Physical and chemical properties of some cherry products:

The operations of cherry juice industry depend on many factors. The thermophysical properties such as density and viscosity are those of importance. Food plant operators and food engineers use these data to maintain a standard products quality level. Results recorded in Table (5.31) show some physical and chemical properties of the obtained cherry products. As can be seen from Table 5.31, total solids in cherry puree is higher for the cherry nectars so that the cherry puree content of higher content of total sugars (11.17 %), total pectic substances (2.31 %), ascorbic acid (19.89 mg/100 ml), titratable acidity (1.52 %) and density (1078.09 kg/m3). This result indicates that cherry puree is higher also for viscosity and sensory properties scores. The results were in agreement with those obtained by **Bayindirli and Özsan (1992); Ferrando *et al.*, 1993; Guyer *et al.* (1993)** and **Giner *et al.* (1996).**

Table 5.31: Physical properties and chemical composition of cherry products

Components	Lindavia nectar	Werder nectar	Reichelt nectar	Cherry puree
Moisture %	84.53±0.19	86.14±0.14	84.58±0.23	83.05±0.11
Total solids %	15.47±0.19	13.86±0.14	15.42±0.23	16.95±0.11
Ash %	0.49±0.02	0.39±0.01	0.45±0.00	0.57±0.01
Titratable acidity %	1.32±0.02	1.26±0.01	1.37±0.01	1.52±0.03
pH value	3.17±0.03	2.95±0.04	2.94±0.06	3.34±0.04
Ascorbic acid (mg/100 ml)	12.76±0.22	11.07±0.12	9.11±0.08	19.89±0.26
Total sugars %	10.29±0.35	10.56±0.20	11.08±0.42	11.17±0.33
Reducing sugars %	7.08±0.30	7.44±0.14	7.38±0.37	9.78±0.19
Non-reducing sugars %	3.21	3.12	3.70	1.39
Total pectic substances %	0.96	0.79	0.88	2.31
Water soluble pectin %	0.24±0.01	0.18±0.00	0.23±0.01	0.61±0.02
Ammonium oxalate soluble pectin %	0.54±0.01	0.46±0.01	0.48±0.00	1.32±0.05
Acid soluble pectin %	0.18±0.01	0.15±0.01	0.17±0.01	0.38±0.01
Color index (O.D. at 420 nm)	0.76±0.05	0.94±0.02	0.98±0.04	1.54±0.06
Anthocyanin (mg per 100 g)	428.08±8.64	451±5.29	476±9.12	509±6.31
Specific heat capacity kJ/kg K	1.809±0.02	1.779±0.03	1.806±0.03	1.833±0.02
Density at temperature 5 °C (kg/m^3)	1072.11±1.90	1063.72±2.71	1071.57±2.37	1078.09±3.11
Density at temperature 30 °C (kg/m^3)	1059.24±1.76	1051.83±1.77	1058.03±1.09	1065.98±2.66

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

5.7.Sensory evaluation of some Cherry products:

As in all foods, the organoleptic tests are generally the final guide of the quality from the consumers point of view. Thus, it was benefical to make a comparison between cherry products. The mouth feel, color, taste, aroma and overall acceptability were evaluated. In Table 5.32 the results of the sensory tests of cherry products are presented. There is significant difference ($P>0.05$) between cherry puree, juice and nectar. The cherry puree was that which has the best characteristics, compared to the cherry nectar Lindavia which has the worst characteristics. The cherry puree has obtained the higher scores for the overall acceptability and other sensory attributes. In the same time the cherry nectar Lindavia has obtained the lower scores for the overall acceptability and other sensory attributes. These results depended on the effect chemical composition of cherry products.

Table 5.32 Sensory properties of cherry products

Products	Sensory attributes				
	Mouth feel (25)	Color (25)	Taste (25)	Odor (Aroma) (25)	Overall acceptability (100)
Lindavia nectar	18.00 ^{a}±0.728	18.00 ^{a} ±1.193	18.25 ^{a} ±0.922	18.08 ^{a} ±0.874	81.42 ^{a} ±1.384
Werder nectar	20.83 ^{b} ±0.458	20.42 ^{ab} ±1.203	20.00 ^{b} ±0.348	20.00 ^{a} ±1.108	88.08 ^{b} ±1.897
Reichelt nectar	22.92 ^{c} ±0.557	22.17 ^{b} ±1.199	22.75 ^{c} ±0.538	19.33 ^{a} ±1.514	90.25 ^{b} ±2.931
Cherry puree	24.25 ^{d} ±0.305	24.33 ^{bc} ±0.284	24.00 ^{c} ±0.492	24.41 ^{b} ±0.288	98.67 ^{c} ±0.527
L.S .D at P ≤ 0.05	1.482	2.903	1.700	2.896	5.256

Values represent of 12 panellists (Mean ± S.E.)
a, b There is no significant difference (p≥0.05) between any two means have the same superscripts, within the same acceptaptability attribute.

5.8. Rheological behavior of some cherry products at different temperatures:

Viscosity is usually considered an important 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. Rheological properties of foods and their variations with temperature over a wide range of concentrations and other processing conditions are important criterion for proper designing of heat transfer and fluid flow equipment (**Rao *et al.*,1985**). Tables (5.33 and 5.34) lists the magnitudes parameters of Herschel-Bulkley (HB) model, Casson model (CA) and Ostwald model of cherry nectar and puree at all assay temperatures.

Use of Herschel-Bulkley (HB) and Casson models:

Data presented in Table 5.33 showed that the magnitudes of HB and CA parameters increased with increase in total solids and decreased with temperature. The τ_{0HB} values for cherry puree decreased with temperature increasing. It was 3.37 Pa at 0 °C and decreased to 0.5 Pa at 50 °C. While for all cherries nectars it was no good correlation between τ_{0HB} values and temperature, the same results were obtained also by using Casson model. The yield point τ0CA values for CA model were higher than those obtained by HB model for cherry puree, while the yield point values for HB model were higher than those obtained by CA model for all cherry nectars.

The flow index values (n) for the cherry nectar given in Table 5.33 were nearly one indicating that the rheological behavior is non-Newtonian fluid and the degree of structure formation (n = 1 → structure less Newtonian fluid). On the other hand, the flow index values for cherry puree (n) ranged between 0.49 and 0.60. These results indicated that cherry puree behavior as pseudoplastic fluid. The flow index values decreased with increasing total solids and pectin content, same results also obtained by **Abd El-Salam (1999); El-Mansy *et al.*(2000b).**

The thixtropy values (Pa/s) decreased with increasing the temperature for cherry puree which were 212.02, 184.20, 146.35, 162.56, 142.75 and 84.50 Pa/s at all assay temperatures 0,10, 20, 30, 40 and 50 °C, respectively.

Cherry puree showed the greatest values of shear stresses in the given range of shear rates (Figs.5.37-40), a high value of the Casson yield stress, markedly highest Casson plastic viscosity, and the highest consistency coefficient of HB model. It also had the largest area of the thixotropy hysteresis (Table 5.33). The rheological parameters of this sample correlated well with its physicochemical features (Table 5.31). the other cherries nectar exhibited much lower values of Casson yield stress, Casson plastic viscosity and Casson effective viscosity (ηCA).

Use of Ostwald Model:

The rheological properties of fluid foods are key parameters required to solve food industry problems in numerous areas: quality control, evaluation of consumer acceptance or texture. From the given Figs.5.37-40 measured at different temperatures it appeared that shear stress vs shear rate curves were non linear which related to non Newtonian behavior. The flow data fitted to the Ostwald model in all cases the correlation coefficients was higher than ($r > 0.91$) showing increased pseudoplasticity for cherry puree ($0.20 < P < 0.25$), when all cherry nectars samples the values of P ranged between (0.43 to 0.71). This increase in pseudoplasticity for cherry puree can be attributed to the behavior of pectin. The flow index (P) values increased by increasing temperature in the case of cherry puree. It increased from 0.20 at 10 °C to 0.25 at 50 °C. On the other hand, the flow index (P) values decreased with total solids increase. The consistency index (m) values decreased with increasing temperature, while it increased with increasing total solids. Where, it were 5.04, 4.79, 3.43, 2.40, 1.42 and 0.70 Pa.sn for cherry puree and 0.0092, 0.0071, 0,0071, 0.0086, 0.0056 and 0.0047 Pa.sn for Lindavia cherry nectar at temperature 0, 10, 20, 30, 40 and 50 °C, respectively.

Table(5.33) Herschel- Bulkley and Casson Parameters of some Selected Cherry Products

Product	T	Herschel-Bulkley						Casson					A_{TH}
		τ_0	K	n	r	S.D.	$\eta_{eff.}$	τ_0	η_{CA}	r	S.D.	$\eta_{eff.}$	
	°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
Cherry puree	0	3.3662	1.1616	0.5053	0.9992	0.1245	0.1527	3.8589	0.0415	0.9958	0.2868	0.1601	212.0223
	10	3.2981	1.0419	0.4990	0.9988	0.1323	0.1367	3.7526	0.0339	0.9962	0.2352	0.1428	184.2025
	20	2.3825	0.7211	0.5086	0.9984	0.1104	0.0988	2.6761	0.0248	0.9969	0.1569	0.1031	146.3488
	30	1.7069	0.4605	0.5392	0.9985	0.0811	0.0722	1.8481	0.0189	0.9982	0.0887	0.0748	162.5652
	40	1.0367	0.2434	0.5784	0.9992	0.0390	0.0453	1.0738	0.0126	0.9993	0.0364	0.0466	142.7476
	50	0.4976	0.1232	0.6089	0.9990	0.0250	0.0253	0.5039	0.0081	0.9995	0.0176	0.0259	84.4978
Reichelt sour cherry nectar	0	0.0032	0.0033	0.9663	0.9979	0.0056	0.0029	0.0017	0.0023	0.9935	0.0092	0.0027	0.0294
	10	0.0017	0.0026	0.9478	0.9968	0.0049	0.0021	0.0009	0.0017	0.9949	0.0060	0.0020	0.0937
	20	0.0017	0.0019	0.9495	0.9941	0.0049	0.0015	0.0010	0.0013	0.9913	0.0058	0.0015	0.0982
	30	0.0040	0.0009	1.0627	0.9904	0.0048	0.0012	0.0022	0.0008	0.9704	0.0079	0.0011	0.1861
	40	0.0022	0.0008	1.0358	0.9864	0.0044	0.0010	0.0013	0.0007	0.9734	0.0061	0.0009	0.0865
	50	0.0042	0.0003	1.2406	0.9770	0.0049	0.0010	0.0021	0.0005	0.9414	0.0073	0.0007	0.0940
Werder sour cherry nectar	0	0.0038	0.0029	0.9813	0.9980	0.0050	0.0027	0.0021	0.0021	0.9911	0.0098	0.0025	0.1757
	10	0.0019	0.0028	0.9236	0.9967	0.0048	0.0020	0.0011	0.0017	0.9960	0.0052	0.002	0.2289
	20	0.0054	0.0014	1.0064	0.9946	0.0045	0.0015	0.0032	0.0010	0.9799	0.0082	0.0014	0.3366
	30	0.0085	0.0008	1.0833	0.9912	0.0044	0.0013	0.0049	0.0006	0.9682	0.0080	0.001	0.1033
	40	0.0014	0.0010	0.9867	0.9862	0.0044	0.0010	0.0008	0.0007	0.9800	0.0052	0.0009	0.1444
	50	0.0020	0.0005	1.0868	0.9821	0.0041	0.0008	0.0012	0.0005	0.9663	0.0054	0.0007	0.1514
Lindavia sour cherry nectar	0	0.0034	0.0030	0.9895	0.9987	0.0044	0.0029	0.0018	0.0023	0.9920	0.0098	0.0027	0.0874
	10	0.0020	0.0024	0.9689	0.9971	0.0047	0.0021	0.0011	0.0017	0.9929	0.0069	0.002	0.0808
	20	0.0030	0.0014	1.0188	0.9957	0.0042	0.0016	0.0016	0.0011	0.9823	0.0079	0.0014	0.0827
	30	0.0048	0.0011	1.0219	0.9935	0.0042	0.0013	0.0028	0.0008	0.9771	0.0074	0.0011	0.2419
	40	0.0028	0.0007	1.0622	0.9892	0.0041	0.0010	0.0016	0.0006	0.9707	0.0063	0.0008	0.1334
	50	0.0022	0.0006	1.0718	0.9892	0.0042	0.0009	0.0013	0.0006	0.9688	0.0057	0.0008	0.2595

Table(5. 34) Ostwald Parameters of some Selected Cherry Products

Product	T	Ostwald Parameters			
		m	P	S.D.	r
	°C	$Pa.s^n$	-	Pa	-
Cherry puree	0	5.0387	0.2174	0.9472	0.9526
	10	4.7928	0.2049	0.8459	0.9501
	20	3.4264	0.2067	0.6314	0.9475
	30	2.4022	0.2133	0.4963	0.9418
	40	1.4256	0.2219	0.3329	0.9364
	50	0.7021	0.2466	0.1991	0.9346
Reichelt cherry nectar	0	0.0105	0.6761	0.0250	0.9530
	10	0.0068	0.7011	0.0162	0.9610
	20	0.0059	0.6682	0.0137	0.9516
	30	0.0073	0.5417	0.0149	0.9094
	40	0.0050	0.5864	0.0111	0.9169
	50	0.0062	0.4846	0.0117	0.9626
Werder cherry nectar	0	0.0108	0.6495	0.0254	0.9442
	10	0.0073	0.6803	0.0156	0.9619
	20	0.0100	0.5255	0.0180	0.9065
	30	0.0117	0.4324	0.0162	0.9724
	40	0.0041	0.6290	0.0096	0.9333
	50	0.0043	0.5693	0.0093	0.9090
Lindavia cherry nectar	0	0.0092	0.7078	0.0234	0.9590
	10	0.0071	0.6919	0.0176	0.9552
	20	0.0071	0.6125	0.0167	0.9256
	30	0.0086	0.5215	0.0156	0.9056
	40	0.0056	0.5583	0.0118	0.9051
	50	0.0047	0.5693	0.0101	0.9104

The Ostwald model equation was found a good model to describe the flow behavior of cherries products. These results were in agreement with **Saravacos and Kostaropoulos (1995)** who reported that most fruit and vegetable fluids and pastes are pseudoplastic, where the flow behavior index varies between 0 and 1. The consistency index increases exponentially with the total solids of the juice and it decreases sharply at higher temperatures. Temperature has a relatively small effect on the flow behavior index of non-Newtonian (pseudoplastic) fluids. In addition, **Ibarz *et al.*(1987, 1989, 1992a,b, 1994, 1995 and 1996a,b)** reported that temperature was found to have a large effect on the consistency index but with a little effect on the flow behavior index.

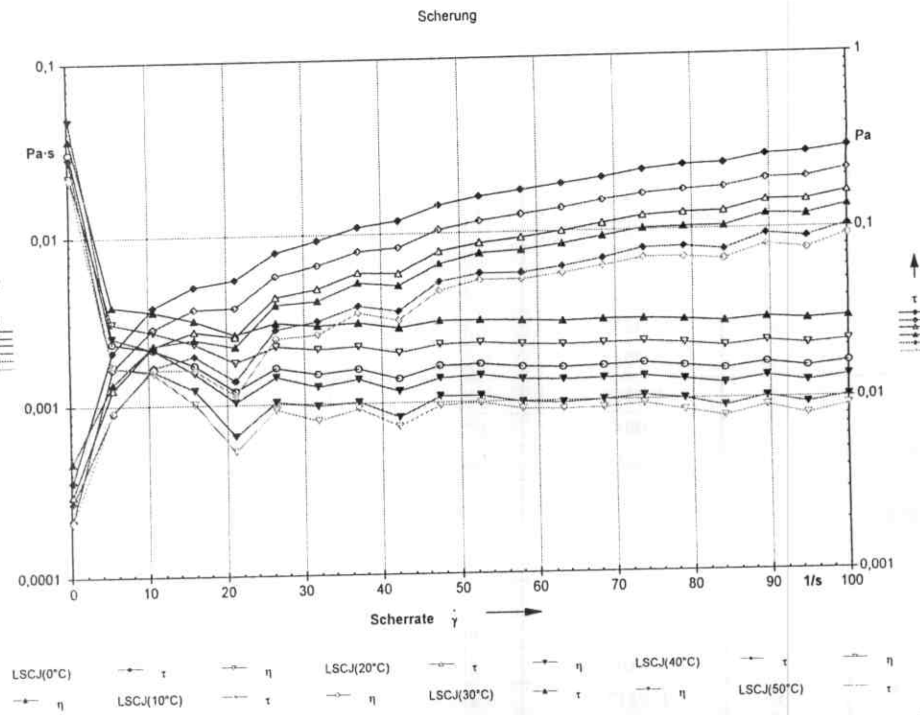


Fig. 5.37: The flow and viscosity curves for the Lindavia cherry nectar at all investigated temperatures.

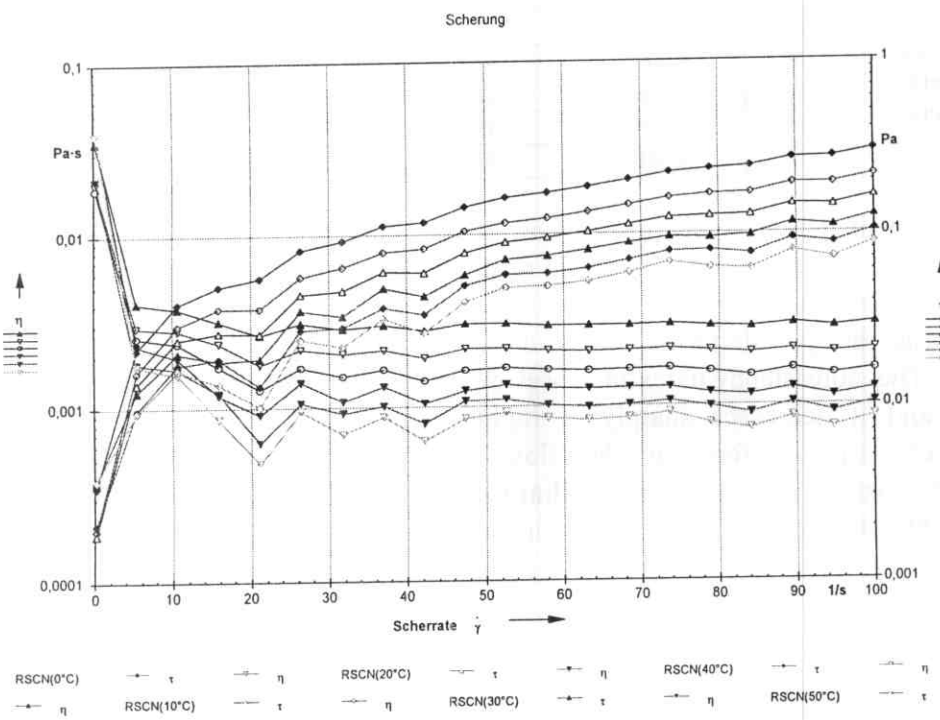


Fig. 5.38: The flow and viscosity curves for the Reichelt cherry nectar at all investigated temperatures.

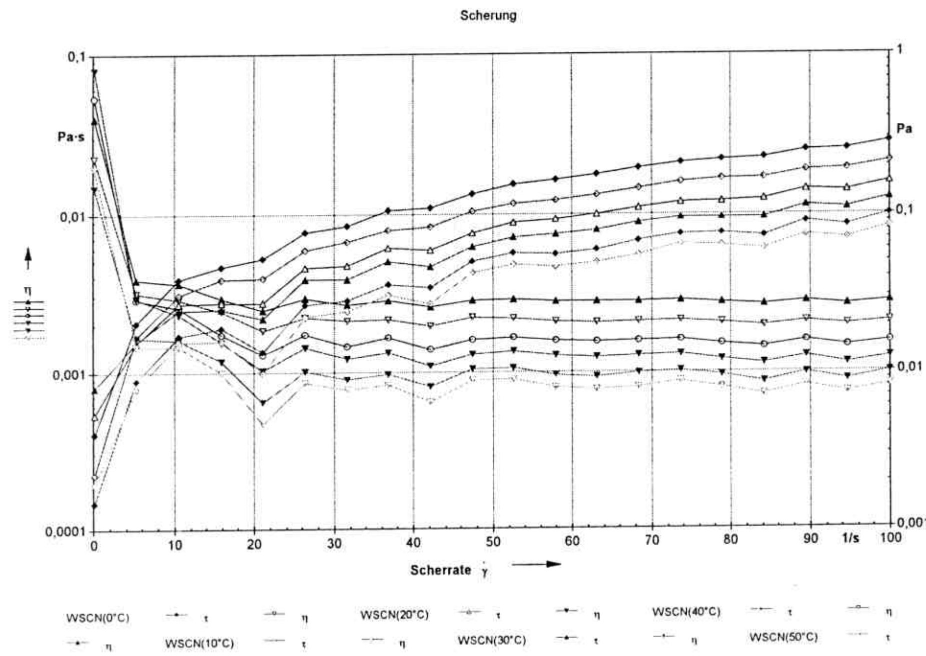


Fig. 5.39: The flow and viscosity curves for the Werder cherry nectar at all investigated temperatures.

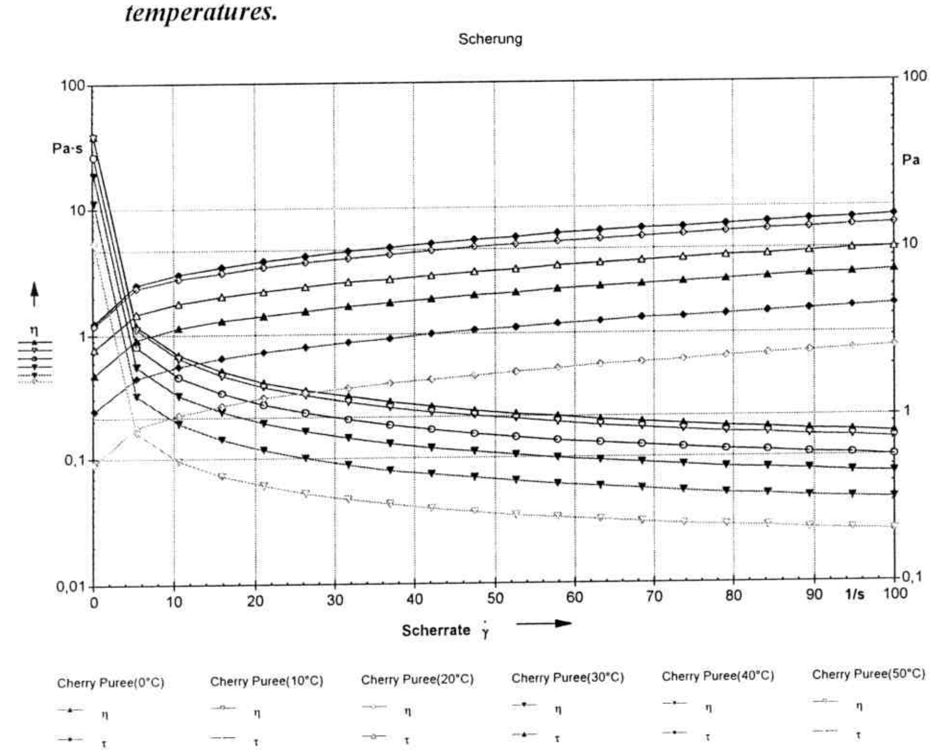


Fig. 5.40: The flow and viscosity curves for the cherry puree at all investigated temperatures.

5.9.Activation energy and the effect of temperature on viscosity of some cherry products:

It is well known experimentally that the viscosity of fluids decreases with increasing temperature. Because heat treatment is a major aspect of much of food processing. The effect of temperature on the flow behavior of cherry products was described by Arrhenius relationship eqn. (4.9). The parameters of this equation are shown in Table 5.35. The activation energy increased with the total solid .it can be observed that the effect of temperature in decreasing the viscosity of cherry products was more pronounced at higher total solid. This tendency is similar to other juices (**Ibarz *et al.*, 1994**; **1992a,b**; **Giner *et al.*, 1996**; **Kaya 2001**). Viscosity, as expected, decreased with increasing temperature. The regression analysis shows that the Arrhenius equation was applicable for all samples ($R^2 \geq 0.97$). The range of calculated Ea was 17.52 to 25.99 kJ/ mole. The results were showed in agreement with those obtained by **Özilgen and Bayindirli (1992)** they found the Ea ranged between 14.8 to 18.5 kJ/mol, for sour cherry juice

Table (5.35) Arrhenius-type constants relating the effect of temperature and viscosity at 100 RPM on cherry products

Products	Ea (kJ/mol)	η_∞ (mPa.s)	Coefficient of Correlation (R^2)	Temperature range °C
Lindavia cherry nectar	17.5151	-6.6709	0.9957	0 - 50
Werder cherry nectar	18.0164	-6.9231	0.9994	0 - 50
Reichelt cherry nectar	18.2235	-6.9722	0.9973	0 - 50
Cherry puree	25.9896	-6.1932	0.9656	0 - 50

5.10.Mechanical properties of cherry fruits:

5.10.1.Effect of cherry varieties and storage at different temperatures on mechanical properties of cherry fruits:

Cherries are soft fleshy fruits with a stone. Cherry pulp is much softer than the skin. The water content of the flesh is about 90 %, and its modulus of elasticity is in some cases only one hundredth of the modulus of elasticity of the fruit skin (**Blahovec *et al.*1995**). These special characteristics give the cherry certain properties of fibrosity, turgidity, and inelasticity which make it difficult to perform mechanical assays to reach a correct assessment of texture differences between different degrees of ripening for a specific variety of cherry, and also between different varieties of this species. While a considerable part of the cherry production is exported, the expansion of fresh cherry exports is hampered by relatively short storage life of this fruit (**Paull, 1999**).

In this part of study, we have tested some mechanical parameters of some varieties of sweet and sour cherry by using compression test. Also study the effect of storage under different conditions on the mechanical parameters of cherry. The mechanical properties of cherries fruits were measured until all fruits were very firm when touched by hand. It is very difficult to determine the texture. The data obtained in the compression test are given in Tables (5.36-39) and Figs.(5.41-46). The mean values of 50 fruits samples and standard errors are given.

Firmness results were expressed as the maximum force (N) to compression of a whole cherries, Young's modulus(Chord) is obtained from the slope of a "least squares fit" straight line, made through the steepest linear region of the testing curve between 2-6 mm, and the Energy (the area under loading curve to between the 2-10mm). The significantly different between cherry varieties during chilling and nonchilling storage in all physico-mechanical parameters under investigation.

The maximum compression force varied from 26.97 N (Spanish sweet cherry) to 16.94 N (Werder German sweet cherry). The Young's modulus (Chord) ranged from 0.0315 MPa (Spanish sweet cherry) to 0.0197 MPa (Werder German sweet cherry). The maximum compression force and all mechanical parameters decreased with time of storage increasing for all cherry varieties under assay. It is clear from Tables (5.36-5.39), chilling conditions effected on shelf live for all cherry varieties. Cherry stored in nonchilling storage were softer than the cherries stored at the chilling conditions. **Cliff *et al.*(1996)** although cherry condition and freshness have been identified as quality factors in consumer purchase decisions, they should not be a factor in cultivar selection, cherry color, size and texture are the most in consumer acceptability.

German sweet cherry fruits (*Prunus avium L.*):

The German sweet cherry fruits have a diameter (width) ranged from 2.45 to2.29 cm, and a length ranged from 2.82 to 2.42 cm, the diameter and length are the mean values of the 50 fruits samples Table (5.36). After 15 days storage at 4 ± 0.5 °C, 90 ± 5% relative humidity (C, chilled) the maximum force values of the cherries decreased, and all mechanical parameters were decreased with increasing in the storage time. In general, texture change during the storage of fruit involved cell wall degradation, which consisted of a dissolution of the pectin-rich middle lamella region. These results were in agreement with **Bartley and Knee, 1982 ; Bernalte *et al.*, 2003**.

Table 5.36 Physico-mechanical parameters for Werder German sweet cherry fruits (*Prunus avium L.*) stored under different conditions:

Treatment	Storage time	Weight	Diameter	Length	Maximum Force	Young's Modulus (Chord)	Energy (2-10mm)
	(days)	gm	cm	cm	N	MPa	J
Control	0	7.458±0.097	2.45±0.050	2.82±0.047	16.94±0.67	0.0197±0.001	0.0915±0.002
Chilled 4 °C	1	7.295±0.151	2.40±0.025	2.78±0.041	15.92±0.70	0.0197±0.000	0.0914±0.002
	2	7.318±0.174	2.42±0.046	2.75±0.057	15.30±0.40	0.0189±0.001	0.0913±0.002
	3	7.337±0.180	2.45±0.043	2.73±0.055	14.98±0.31	0.0177±0.001	0.0904±0.001
	4	7.263±0.132	2.44±0.032	2.68±0.052	14.45±0.46	0.0176±0.001	0.0874±0.002
	5	7.197±0.169	2.41±0.016	2.65±0.036	13.71±0.34	0.0167±0.001	0.0784±0.003
	6	7.186±0.251	2.39±0.072	2.66±0.058	13.35±0.29	0.0157±0.001	0.0781±0.002
	7	7.172±0.144	2.37±0.044	2.61±0.059	12.73±0.38	0.015±0.0004	0.0744±0.002
	8	7.176±0.183	2.38±0.054	2.58±0.027	11.83±0.27	0.0143±0.001	0.0722±0.001
	9	7.146±0.161	2.35±0.044	2.60±0.048	11.12±0.27	0.0135±0.000	0.0712±0.001
	10	7.185±0.135	2.37±0.037	2.59±0.024	10.76±0.25	0.0128±0.000	0.0699±0.002
	11	7.184±0.168	2.38±0.029	2.57±0.036	10.43±0.41	0.0118±0.000	0.0675±0.001
	12	7.174±0.178	2.35±0.022	2.56±0.042	10.17±0.26	0.0106±0.001	0.0644±0.002
	13	7.096±0.218	2.34±0.023	2.54±0.039	9.44±0.288	0.0098±0.000	0.0608±0.001
	14	6.961±0.140	2.25±0.037	2.45±0.023	8.48±0.35	0.0091±0.000	0.0543±0.002
	15	7.008±0.125	2.29±0.046	2.43±0.044	7.51±0.19	0.0085±0.001	0.052±0.0012
Nonchilled 25 °C	1	7.465±0.135	2.47±0.045	2.80±0.033	15.36±0.42	0.0183±0.001	0.0877±0.003
	2	7.324±0.173	2.46±0.019	2.79±0.024	14.69±0.32	0.0177±0.001	0.0842±0.002
	3	7.286±0.167	2.44±0.023	2.75±0.051	14.36±0.34	0.0173±0.001	0.0839±0.002
	4	7.263±0.151	2.42±0.026	2.75±0.047	13.06±0.47	0.0149±0.001	0.0772±0.002
	5	7.261±0.194	2.39±0.038	2.69±0.044	11.86±0.44	0.0136±0.001	0.0686±0.003
	6	7.096±0.204	2.35±0.041	2.65±0.036	10.65±0.38	0.0114±0.001	0.056±0.003
	7	7.082±0.117	2.28±0.026	2.59±0.052	9.94±0.40	0.0102±0.000	0.0506±0.002
	8	6.991±0.222	2.29±0.054	2.47±0.067	6.91±0.50	0.008±0.000	0.0367±0.001

On the other hand the cherries were stored at room temperature 25 ± 0.5 °C, 90 ± 5% relative humidity (NC, non-chilled) stayed only 8 days. The change in all mechanical parameters for NC cherry was higher than C cherry. These results caused by correlation between enzyme activity and chilling. **Bernalte *et al.* (2003)** suggested that the drop in enzyme activity during chilling increasing the storage life for cherry fruits from 15 to 8 days for chilled and non chilled cherry, respectively. This fact suggests that the chilled cherry fruit, after 15 days of storage, should not stay at the point of sale. While non chilled cherry fruit stay 8 days only. From the results of this part of study, the temperature and conditions of storage must be controlled during the storage of cherry fruit.

Spanish sweet cherry fruits (*Prunus avium L.*):

Little is known about the influence of storage and variety on mechanical parameters of cherry fruits. Recently, there has been much interest in new sweet cherry cultivars from around the world to fill various marketing niches by extending the maturity season and to solve production problems, such as rain-induced cracking, shelf-incompatibility, and fruit softness, **Kappel *et al.* (1996).** What constitutes a "good" sweet cherry cultivar's is open to debate, but fruit size and texture are all considered important fruit quality traits, **Christensen (1995).**

Table 5.37 Physico-mechanical parameters for Spanish sweet cherry fruits (*Prunus avium L.*) stored under different conditions:

Treatment	Storage time	Weight	Diameter	Length	Maximum Force	Young's Modulus (Chord)	Energy (2-10mm)
	(days)	gm	cm	cm	N	MPa	J
Control	0	9.108±0.160	2.41±0.048	3.02±0.065	26.97±0.41	0.0315±0.001	0.1114±0.004
Chilled 4 °C	1	9.105±0.191	2.43±0.051	3.01±0.038	25.50±0.42	0.0299±0.001	0.1057±0.004
	2	8.999±0.265	2.41±0.022	2.96±0.052	23.91±0.47	0.0269±0.001	0.103±0.004
	3	8.972±0.253	2.40±0.064	2.93±0.043	22.39±0.45	0.0242±0.001	0.0985±0.003
	4	8.831±0.24	2.36±0.047	2.92±0.041	20.92±0.42	0.0229±0.004	0.0904±0.002
	5	8.781±0.179	2.37±0.037	2.87±0.032	18.37±0.60	0.0202±0.001	0.0856±0.003
	6	8.709±0.138	2.37±0.053	2.82±0.021	15.57±0.52	0.0186±0.001	0.0777±0.003
	7	8.704±0.142	2.35±0.019	2.83±0.064	13.82±0.62	0.0153±0.001	0.0684±0.004
	8	8.662±0.162	2.32±0.038	2.80±0.046	12.26±0.51	0.0149±0.001	0.0565±0.004
	9	8.627±0.136	2.30±0.032	2.77±0.016	12.20±0.44	0.0136±0.001	0.0508±0.002
	10	8.549±0.186	2.24±0.075	2.78±0.068	10.72±0.47	0.0116±0.001	0.0457±0.002
	11	8.518±0.189	2.25±0.038	2.74±0.029	8.00±0.34	0.0089±0.000	0.034±0.002
	12	8.552±0.107	2.25±0.028	2.76±0.033	7.17±0.15	0.0081±0.000	0.0323±0.001
	13	8.533±0.168	2.24±0.021	2.75±0.024	6.83±0.49	0.0069±0.001	0.0304±0.004
Nonchilled 25 °C	1	8.977±0.182	2.40±0.072	3.00±0.051	23.52±0.44	0.0274±0.001	0.0977±0.003
	2	8.944±0.233	2.38±0.063	2.97±0.062	21.06±0.54	0.0201±0.000	0.0819±0.003
	3	8.857±0.237	2.35±0.068	2.89±0.054	13.69±0.50	0.0143±0.001	0.0663±0.003
	4	8.791±0.123	2.31±0.042	2.83±0.048	9.90±0.56	0.0114±0.001	0.0386±0.003
	5	8.782±0.148	2.29±0.051	2.79±0.057	8.41±0.55	0.0087±0.000	0.0318±0.002
	6	8.725±0.164	2.27±0.064	2.79±0.059	6.36±0.47	0.0071±0.005	0.0273±0.004

The results of physico-mechanical parameters for Spanish sweet cherry fruits in Table 5.37. Fruit weight average ranged between 9.11 to 8.53 g, fruit diameter ranged between 2.41 to 2.24 cm and fruit length ranged between 3.02 to 2.75 cm, these results were agreement with **Yamaguchi *et al.* (2002); Christensen, 1995; Kappel *et al.* (1996); Drake and Fellman (1987)** they found a significant correlations between cherry fruit weight and firmness. In Werder sweet cherry fruits the weight ranged between 7.40 to 6.96 g and the maximum force ranged between 16.94 to 6.91 N. While the Spanish cherry weight ranged between 9.11 to 8.52 g and the maximum force ranged between 26.97 to 6.36 N. The same results also obtained in Young's Modulus and energy. The values of those parameters in Spanish cherry were higher than the same parameters in Werder cherry.

Greece sweet cherry fruits(*Prunus avium L.*):

Fruit weight can be used to indicate maturity and is correlated with total solid in cherry fruit. In Table 5.38 some physico-mechanical parameters for Greece sweet cherry fruits were showed.

The weight loss during storage was 9.87 % and 7.04 % for chilled and nonchilled, respectively. Greece cherry fruits. The diameter loss was 7.76 % and 4.70 %, the length loss was 9.68 % and 2.94 % for chilled and nonchilled, respectively. While the loss in texture parameters was higher loss during storage. The maximum force loss during storage was 72.65 % and 69.07 %, the young's modulus loss was 65.25 % and 62.64 % and energy loss during storage was 63.13 % and 55.32 % for chilled and nonchilled, respectively. After 6 days storage at C and NC conditions, all the mechanical parameters for Greece cherry presented less loss for C than the NC conditions.

Table 5.38 Physico-Mechanical parameters for Greece sweet cherry fruits (*Prunus avium L.*) stored under different conditions:

Treatment	Storage time	Weight	Diameter	Length	Maximum Force	Young's Modulus (Chord)	Energy (2-10mm)
	(days)	gm	cm	cm	N	MPa	J
Control	0	6.474±0.121	2.32±0.035	2.79±0.036	26.65±0.71	0.0282±0.001	0.0990±0.005
Chilled 4 °C	1	6.219±0.124	2.31±0.044	2.73±0.024	23.87±0.57	0.0269±0.001	0.0821±0.003
	2	6.221±0.145	2.33±0.042	2.71±0.037	22.618±0.61	0.0258±0.001	0.0803±0.002
	3	6.376±0.157	2.31±0.036	2.74±0.059	20.29±0.40	0.0254±0.001	0.0758±0.002
	4	6.178±0.154	2.27±0.047	2.70±0.033	19.97±0.48	0.024±0.001	0.0726±0.002
	5	5.955±0.144	2.22±0.023	2.67±0.021	18.26±0.37	0.0228±0.001	0.0688±0.002
	6	5.997±0.138	2.25±0.021	2.66±0.026	17.69±0.37	0.0215±0.001	0.0657±0.002
	7	5.919±0.103	2.23±0.054	2.64±0.012	16.653±0.44	0.0196±0.001	0.0616±0.002
	8	5.904±0.132	2.21±0.048	2.62±0.019	15.05±0.50	0.0187±0.001	0.0585±0.001
	9	5.909±0.078	2.21±0.017	2.63±0.020	13.35±0.29	0.0158±0.001	0.0553±0.001
	10	5.839±0.112	2.14±0.046	2.59±0.051	12.46±0.30	0.0144±0.001	0.0539±0.002
	11	5.837±0.107	2.15±0.053	2.55±0.074	11.04±0.18	0.0123±0.001	0.0476±0.002
	12	5.833±0.096	2.12±0.027	2.53±0.046	9.68±0.18	0.0106±0.001	0.0455±0.001
	13	5.835±0.111	2.14±0.025	2.52±0.031	7.29±0.29	0.0098±0.000	0.0365±0.002
Nonchilled 25 °C	1	6.403±0.152	2.34±0.022	2.72±0.035	22.86±0.70	0.0265±0.001	0.0808±0.002
	2	6.271±0.191	2.27±0.026	2.67±0.019	19.11±0.68	0.0239±0.001	0.0687±0.002
	3	6.158±0.143	2.23±0.048	2.65±0.050	14.08±0.48	0.0204±0.001	0.0611±0.004
	4	5.911±0.138	2.22±0.042	2.59±0.044	12.51±0.26	0.0180±0.001	0.0501±0.002
	5	5.934±0.127	2.22±0.075	2.62±0.047	10.24±0.32	0.0134±0.001	0.0433±0.001
	6	5.952±0.147	2.23±0.062	2.64±0.069	7.07±0.36	0.0099±0.000	0.0361±0.001

German sour cherry fruit (*Prunus cerasus L.*):

The values of physico-mechanical parameters of German sour cherry fruit are presented in Table 5.39. The firmness (maximum force) of sour cherry was lower after 6 days at nonchilled. While was found the lower after 11 days at chilled condition. All mechanical parameters of German sour cherry fruit decreased with increasing in storage days under two conditions. Decreases in maximum force with storage days was also observed for pear by **Galvis-Sanchez *et al.* (2004).**

Table 5.39 Physico-Mechanical parameters for German sour cherry fruit (*Prunus cerasus L.*) stored under different conditions:

Treatment	Storage time	Weight	Diameter	Length	Maximum Force	Young's Modulus (Chord)	Energy (2-10mm)
	(days)	gm	cm	cm	N	MPa	J
Control	0	5.607±0.183	2.624±0.026	2.135±0.023	19.93±0.48	0.0224±0.001	0.0817±0.002
Chilled 4 °C	1	5.575±0.123	2.456±0.031	2.151±0.025	17.86±0.40	0.0210±0.001	0.0807±0.001
	2	5.363±0.077	2.533±0.034	2.138±0.027	17.20±0.41	0.0182±0.001	0.0741±0.001
	3	5.348±0.076	2.426±0.052	2.085±0.025	16.36±0.56	0.0165±0.001	0.0727±0.002
	4	5.108±0.073	2.381±0.067	2.127±0.028	16.00±0.64	0.0151±0.001	0.0690±0.001
	5	5.096±0.073	2.393±0.041	2.096±0.021	14.58±0.29	0.0120±0.000	0.0617±0.002
	6	5.087±0.073	2.385±0.018	2.125±0.022	13.49±0.41	0.0110±0.000	0.0603±0.002
	7	5.079±0.073	2.354±0.065	2.091±0.019	12.00±0.14	0.0100±0.000	0.0545±0.002
	8	5.026±0.072	2.332±0.018	2.078±0.02	11.20±0.21	0.0089±0.000	0.0519±0.001
	9	4.986±0.069	2.345±0.043	2.082±0.023	10.93±0.24	0.0087±0.001	0.0508±0.002
	10	4.948±0.071	2.317±0.062	2.071±0.02	9.66±0.24	0.0074±0.001	0.0449±0.001
	11	4.997±0.098	2.295±0.041	2.068±0.023	7.53±0.29	0.0067±0.000	0.0281±0.001
Nonchilled 25 °C	1	5.485±0.179	2.545±0.027	2.168±0.026	16.67±0.64	0.0187±0.000	0.0692±0.002
	2	5.335±0.076	2.448±0.021	2.095±0.02	15.15±0.63	0.0163±0.000	0.0652±0.002
	3	5.345±0.076	2.397±0.039	2.016±0.046	12.46±0.45	0.0144±0.001	0.0596±0.002
	4	5.106±0.073	2.353±0.015	2.063±0.023	11.57±0.42	0.0114±0.001	0.0529±0.003
	5	5.089±0.073	2.279±0.047	2.115±0.023	10.57±0.27	0.0105±0.000	0.0517±0.001
	6	5.003±0.146	2.182±0.019	2.075±0.009	7.01±0.15	0.0077±0.000	0.0380±0.001

Conclusions:

Apparently, chilling was the most important factor affecting the texture of cherries fruits, whereas cherry Variety was the secondary factor. The compression test and the mechanical parameters are an excellent indicator for shelf life for cherry. The mechanical parameters are the most useful assay for the correct temperature and time condition for storage and handling of cherry fruits. The maximum compression force is the most suitable single mechanical parameter that can be used to classify the batches unambiguously and to distinguish between varieties. Fruit size is a very important criteria for commercial market value. All tested cherry had a good fruit weight and size. In the end using raw material measurements to describe the quality of a final product would be a great benefit for the industry.

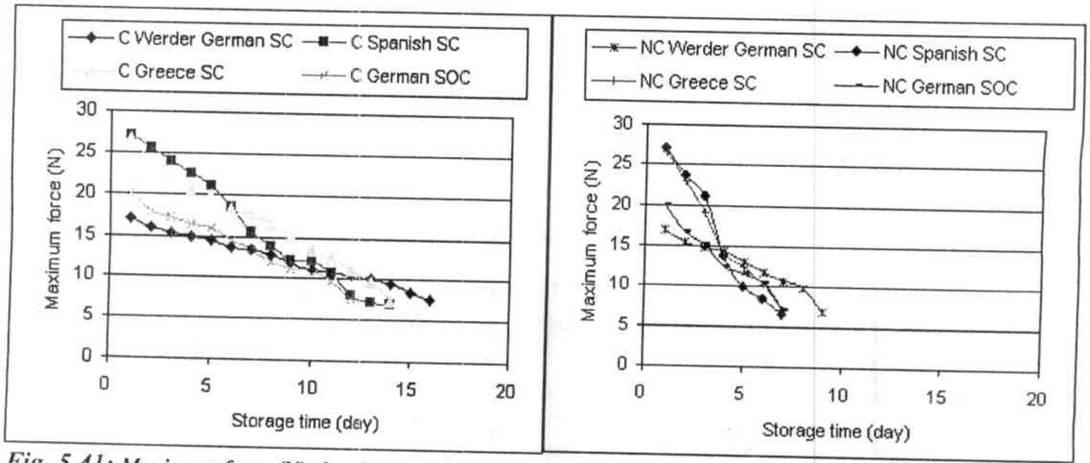


Fig. 5.41: Maximum force (N) for cherry fruits stored at chilled(C) and nonchilled (NC) conditions

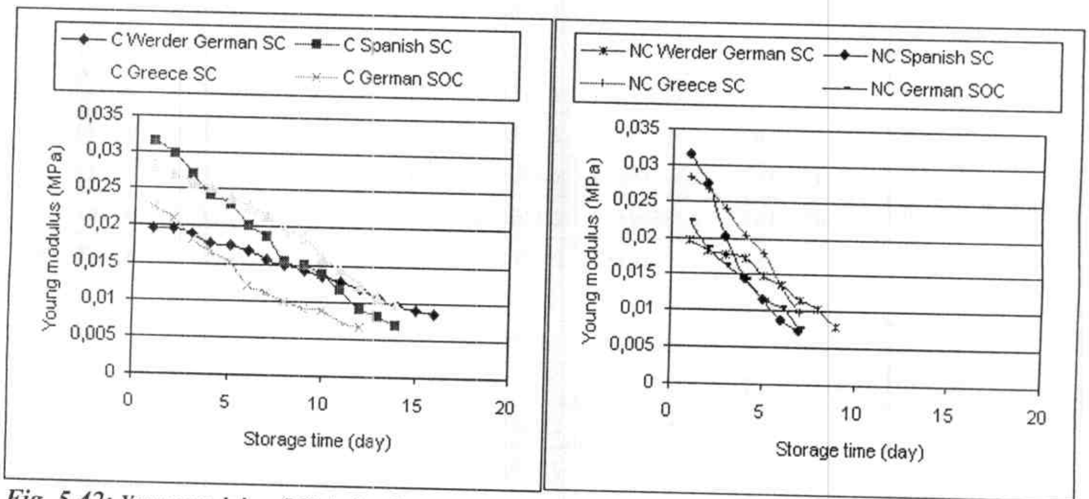


Fig. 5.42: Young modulus (MPa) for cherry fruits stored at chilled(C) and nonchilled (NC) conditions

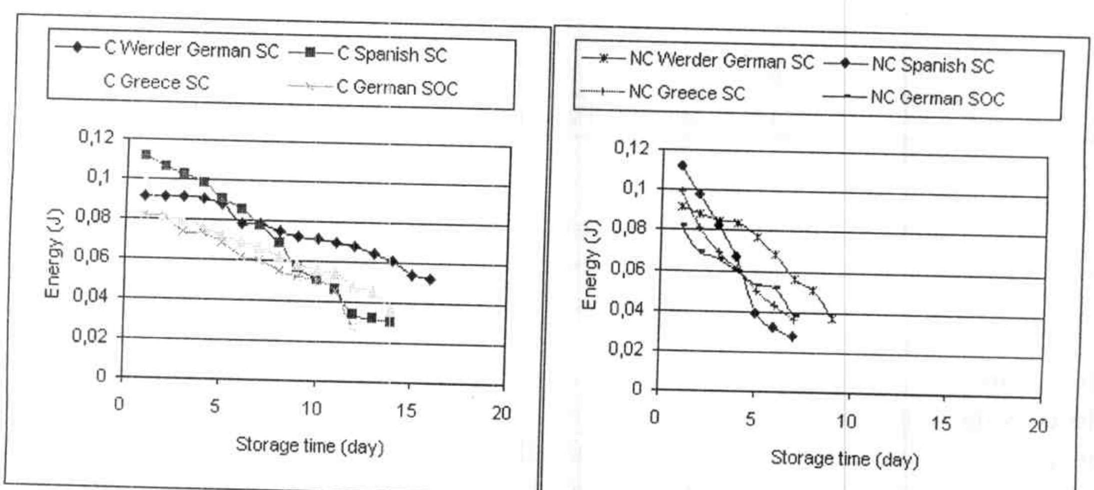


Fig. 5.43: Energy (J) for cherry fruits stored at chilled(C) and nonchilled (NC) conditions

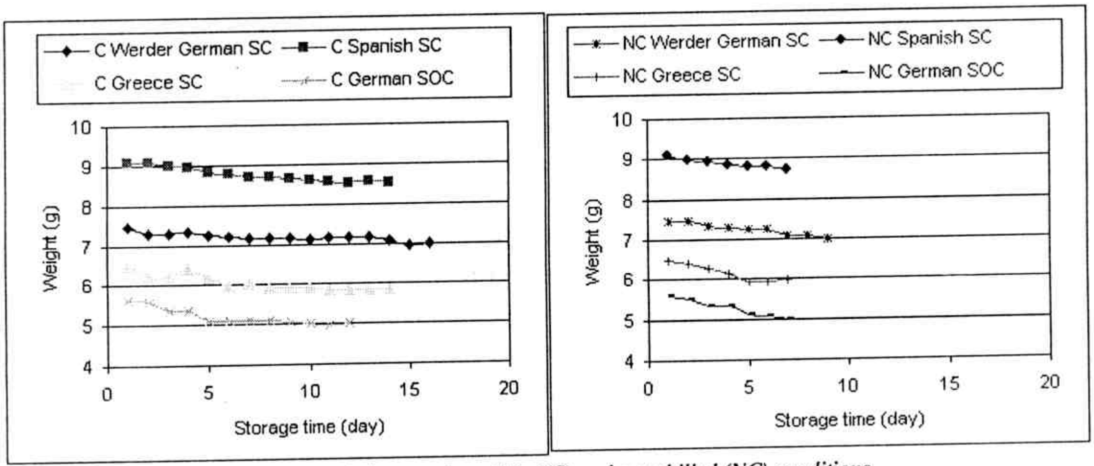


Fig. 5.44: Weight (g) for cherry fruits stored at chilled(C) and nonchilled (NC) conditions

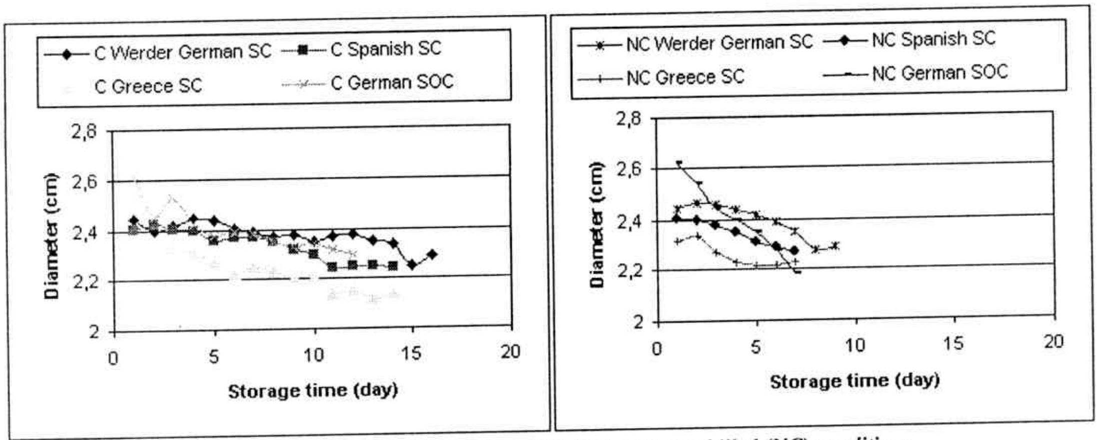


Fig. 5.45: Diameter (cm) for cherry fruits stored at chilled(C) and nonchilled (NC) conditions

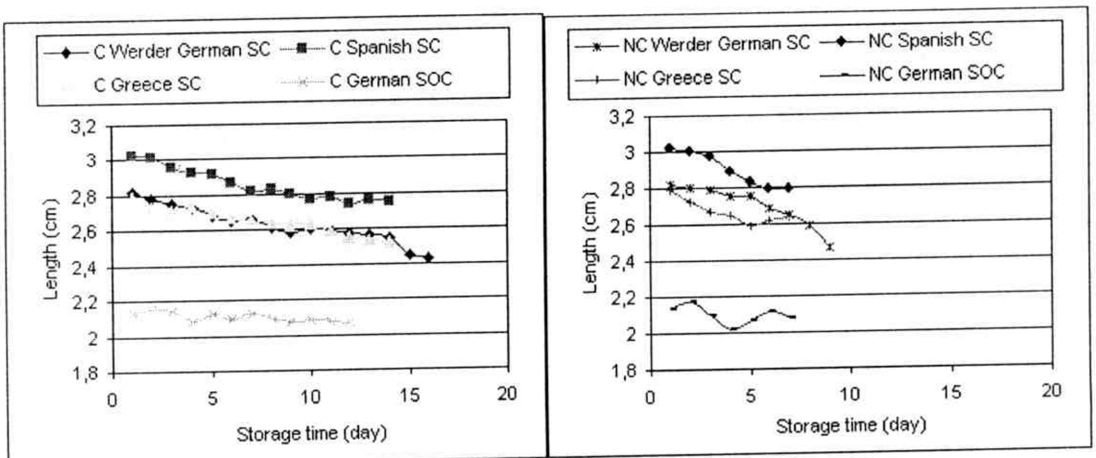


Fig. 5.46: Length (cm) for cherry fruits stored at chilled(C) and nonchilled (NC) conditions

5.10.2.Effect of heat treatment on mechanical properties of cherry fruits:

To studies the effect of the heat treatment on mechanical properties of cherries fruits. Sweet and sour German cherries fruits were used in this part of study. The samples were divided into 6 groups: 5 for heat treatment (50 °C/ 10 min, 60 °C/ 7.5 min, 70 °C/ 5 min, 80 °C/ 2.5 min and 90 °C/ 1.5 min) and one as a control. After preheating the fruits were cooled in tap water, drained and mechanical parameters were massed.

The means and standard errors of the 50 cherry fruits heated at different temperatures and different time were tabulated in Tables 5.40 and 5.41 for sweet and sour German cherries fruits, respectively. Table 5.40 contains the parameters describing the compression curves of heated German sweet cherry.

The Maximum force, Young's Modulus (Chord) and Energy for cherry heated at (90 °C/ 1.5 min) higher than cherry heated at (80 °C/ 2.5 min). Mechanical parameters of sweet cherries at temperatures 50, 60, 70 and 80 °C decreased with temperature increasing. The same results were observed by sour cherries, the mechanical parameters of sour cherries decreased at temperatures 50, 60, 70 and 80 °C. Increased the mechanical parameters of cherries as a result of low- temperature thermal treatment has been attributed to an increase in pectic acid (EDTA-soluble fraction), and to a partial reduction in both soluble pectic material and degree of de-esterification of pectins by pectinesterase,(**Alonso *et al.*,1994 and 1997).** Treatment at low temperature cause loss of membrane selective permeability, giving rise to diffusion of cations to the cell wall(**Alonso *et al.*, 1997**).

Table 5.40 Effect of heat treatment on some physico-mechanical parameters for Werder German sweet cherry fruit (*Prunus avium L.*):

Treatment	Weight	Diameter	Length	Maximum Force	Young's Modulus (Chord)	Energy (2-10mm)
	gm	cm	cm	N	MPa	J
Control	7.46±0.10	2.45±0.05	2.82±0.05	16.94±0.67	0.0197±0.001	0.0915±0.002
50 °C/ 10 min	7.39±0.12	2.47±0.02	2.76±0.04	14.93±0.52	0.0184±0.001	0.0441±0.000
60 °C/ 7.5 min	7.37±0.11	2.46±0.02	2.79±0.04	10.32±0.47	0.0157±0.001	0.0335±0.000
70 °C/ 5 min	7.37±0.15	2.49±0.03	2.72±0.05	9.91±0.42	0.0142±0.000	0.0292±0.001
80 °C/ 2.5 min	7.43±0.14	2.44±0.02	2.84±0.03	9.69±0.47	0.0139±0.000	0.0251±0.001
90 °C/ 1.5 min	7.45±0.14	2.48±0.03	2.82±0.03	9.86±0.44	0.0144±0.000	0.0282±0.000

Table 5.41 Effect of heat treatment on some physico-mechanical parameters for German sour cherry fruit (*Prunus cerasus L.*):

Treatment	Weight	Diameter	Length	Maximum Force	Young's Modulus (Chord)	Energy (2-10mm)
	gm	cm	cm	N	MPa	J
Control	5.61±0.18	2.62±0.03	2.14±0.02	19.93±0.48	0.0224±0.001	0.0817±0.002
50 °C/ 10 min	5.67±0.13	2.46±0.02	2.15±0.03	11.54±0.35	0.0158±0.001	0.0474±0.001
60 °C/ 7.5 min	5.68±0.11	2.53±0.02	2.14±0.02	10.29±0.23	0.0117±0.002	0.0380±0.000
70 °C/ 5 min	5.61±0.11	2.43±0.03	2.09±0.03	9.65±0.27	0.0077±0.001	0.0327±0.001
80 °C/ 2.5 min	5.62±0.13	2.38±0.03	2.13±0.02	9.23±0.42	0.0072±0.001	0.0255±0.001
90 °C/ 1.5 min	5.59±0.11	2.39±0.03	2.10±0.02	10.42±0.34	0.0094±0.001	0.0299±0.001

Apricot and Apricot products

5.11.Physical and chemical properties of Apricot puree:

Results recorded in Table (5.42) show some chemical and physical properties of the obtained apricot puree. Numerous reports on the chemical composition of apricot purees have appeared in the literature but refer to old cultivars which are used less and less by industry. Hence, there is a need to characterize new varieties of apricots, which have been utilized by the food industry for some years. These results of apricot puree were in agreement with **Voi *et al.*, (1995)** who found that the chemical composition of apricot puree ranged from 6.2 to 8.9 % for total sugars, from 3.4 to 4.2 % for pH and from 1.78 to 2.75 % for total acidity. Also the results were in agreement with **Holland *et al.*, (1992)** and **Artik (1993).**

Table 5.42: Chemical composition of Apricot puree

Components	Puree
Moisture %	83.06±0.68
Total solids %	16.94±0.68
Ash %	1.15±0.09
Titratable acidity % (as citric acid)	1.66±0.03
pH value	4.11±0.06
Ascorbic acid (mg/100 ml)	19.84±0.18
Starch%	0.46±0.04
Total sugars %	7.58
Reducing sugars %	2.87±0.11
Non-reducing sugars %	4.71±0.24
Total pectic substances %	3.84
Water soluble pectin %	1.29±0.13
Ammonium oxalate soluble pectin %	1.57±0.08
Acid soluble pectin %	0.98±0.09
Pulp Content (V/V) %	30.17±0.81
Color index (O.D. at 420 nm)	0.7677±0.001
Anthocyanine (O.D.)	0.175±0.002
Carotenoids (mg/L)	29.78±0.13
Specific heat capacity kJ/kg K	1.833±0.04
Density at temperature 5 °C (kg/m^3)	1089.86±0.96
Density at temperature 30 °C (kg/m^3)	1081.09±0.89

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

**Chemical composition on wet weight basis*

5.12.Rheological behavior of apricot puree:

Knowledge of the rheological properties of apricot puree is of value in relation to momentum, heat and mass transfer phenomena and to process and plant design. Equations or mathematical models Herschel-Bulkley, Casson and Ostwald have been widely used in quantifying the flow of fruit products (juices, purees, and concentrates) because of their simplicity and because, in most cases, a plot of log $(\tau - \tau_0)$ or of $\log \tau$ versus $\log \dot{\gamma}$ is a straight line for a wide range of shear rate values. Data obtained by applying both models are of practical value for identifying flow and for engineering design.

Viscosity of apricot puree had a complex non Newtonian pseudoplastic behavior and it decreased as shear rate increased (Fig. 5.47). When the aggregates in a network are broken down by shear forces, the suspended liquid entrapped within the network is released and causes the decrease in viscosity as shear rate increases. Therefore, at an infinite shear rate, the viscosity of a suspension is the viscosity of the suspending medium (**Rha 1975**).

Use of Herschel-Bulkley and Casson models:

The calculation of the rheological parameters was carried out according to the Herschel-Bulkley, and Casson models. There was no good correlation between temperature and HB-consistency index (K) value for apricot puree, while it was a good correlation between τ_{0HB}, τ_{0CA} and temperature. The yield stress decreased with temperature in H-B and CA models. These results were agreement with **Duran and Costell (1982); Castaldo *et al.*(1990).** To completely characterize the flow of fruit products it is important to take into account the value of the yield stress in those products which show this characteristic. Thixotropy values are tabulated also in Table 5.43. Apricot puree exhibits thixotropic properties. The thixotropy decreased as temperature increasing, it was 280.55 and 22.60 Pa/s at 0 and 50 °C, respectively.

Table 5.43 Herschel-Bulkley and Casson parameters of apricot puree

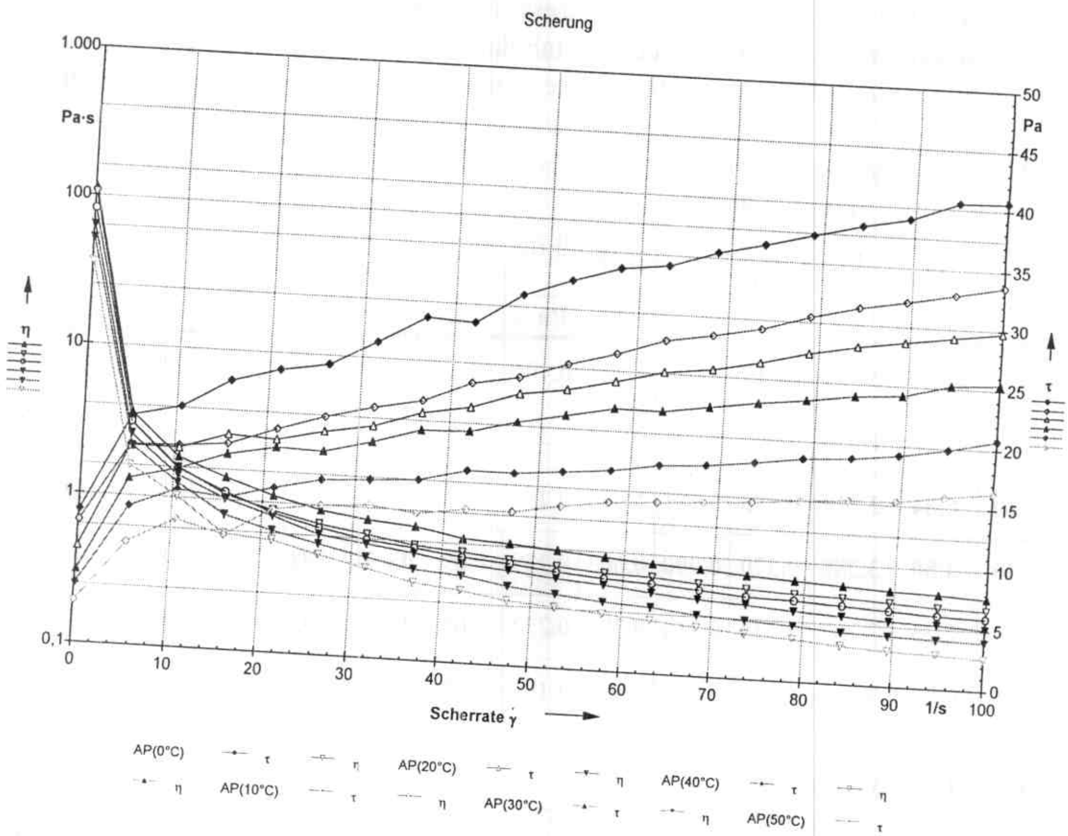
T	Herschel-Bulkley						Casson					A_{TH}
	τ_0	K	n	r	S.D.	η_{eff}	τ_0	η_{CA}	r	S.D.	η_{eff}	
°C	Pa	Pa.s^n	-	-	Pa	Pa s	Pa	Pa.s	-	Pa	Pa.s	Pa/s
0	10.53	2.854	0.510	0.996	0.741	0.405	11.68	0.094	0.995	0.811	0.420	280.55
10	10.38	1.380	0.607	0.992	0.793	0.330	10.24	0.066	0.994	0.716	0.332	239.53
20	6.84	3.714	0.383	0.981	1.016	0.285	9.38	0.061	0.979	1.077	0.305	168.66
30	4.80	3.288	0.370	0.990	0.603	0.229	8.59	0.056	0.929	1.660	0.281	108.58
40	2.33	7.767	0.234	0.984	0.799	0.252	7.06	0.053	0.981	0.838	0.247	53.77
50	0.95	6.842	0.214	0.985	0.591	0.192	6.52	0.044	0.932	1.248	0.216	22.60

Use of Ostwald model:

From the given Fig.5.47 measured at different temperatures it appears that shear stress vs shear rate curves for apricot puree were non linear which related to non Newtonian behavior. The viscosity was decreased with increasing shear rate. It showed pseudoplastic behavior and slightly time-dependent at all assayed temperatures. The flow data fitted to the Ostwald model which is very simple and is used extensively in engineering applications. In all cases the correlation coefficients was higher than (r > 0.91), Table 5.44. The flow index values lie in the range: (0.18 < P < 0.19). There was no effect of temperature on the flow behavior index. The consistency index was decreased as temperature increased. In this case the Ostwald model was most successful.

Table 5.44 Ostwald parameters of apricot puree

Product	T	Ostwald Parameters			
	°C	m Pa.s^n	P	S.D. Pa	r
Apricot puree	0	14.6921	0.1969	2.6472	0.9422
	10	12.7241	0.1779	2.6285	0.9083
	20	11.4321	0.1851	1.6612	0.9500
	30	8.7201	0.1969	1.1376	0.9651
	40	10.3734	0.1900	0.8629	0.9814
	50	7.9064	0.1920	0.6187	0.9838



(Fig. 5.47) The flow and viscosity curves for the apricot puree at all investigated temperatures.

5.13. Activation energy and the effect of temperature on viscosity of apricot puree:

Design of equipment for fluid flow and heat transfer operations involved in the manufacture of apricot puree require data on the rheological properties of this product. The viscosity of apricot puree decreased with temperature. The Ea of apricot puree was 9.68 (kJ/mol) with coefficient of correlation (R^2) 0.997, Table 5.45.

Table 5.45 Arrhenius-Type Constants Relating the Effect of Temperature and Viscosity at 100 RPM on Apricot Puree

Products	Ea (kJ/mol)	η_∞ (mPa.s)	Coefficient of Correlation(R^2)	Temperature range °C
Apricot puree	9.675	1.762	0.9969	0 - 50

5.14. Oscillation tests:

Figs. 5.48-49 shows the changes in storage modulus (G′), loss modulus (G′′) and tan δ as a functions of the frequency for apricot puree at 0, 10, 20, 30, 40 and 50 °C.

Frequency sweeps(FS):

The oscillatory test is carried out with frequency range $10E^{-3}$ to 100 Hz and at temperature 0, 10, 20, 30, 40 and 50 °C Figs. (5.48-49). The dynamic moduli G′, G′′ and tan δ as a function of frequency (f) are plotted in Fig. 5.48 for the apricot puree. Apricot puree is clearly viscoelastic. The dynamic parameters including tan δ increase with increasing f. At low f tan δ has lower values indicating a more solid like behavior. A possible, but at present hypothetical explanation for the 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. The dynamic rheological data of ln (G′, G′′) versus ln frequency for apricot puree at different temperature (0 –50 °C) were also subjected to linear regression, as suggested by **Rao and Cooley (1992) and Yoo (2004)**. Table 5.46 contains the magnitudes of slopes (x′ and y′′), intercepts (K_1' and K_2''), and R^2 for the following equations:

$$G' = K_1'(\omega)^{x'} \qquad (4.6)$$

$$G'' = K_2''(\omega)^{y''} \qquad (4.7)$$

From these dynamic rheological data, it was found that the apricot puree displayed a more solid like behavior because the magnitudes of K_1' are much higher than those of K_2'' with a high dependence on frequency. Also from a structural point of view, such plots for true gels have near zero slopes, while for weak gels they have positive slopes (**Giboreau *et al.*1994**). The magnitudes of K_1' and K_2'' also decreased with increase in temperature. It is a well-known phenomenon that increasing temperature would decrease the viscosity of many fluid foods due to an increase in kinetic energy (**Katsuta and Kinsella, 1990**). The dependence on temperature of G′, G′′ appeared to follow the usual expectation of decreasing G′, G′′ with increase in temperature with a high dependency on frequency.

Table 5.46 Dynamic shear data of apricot puree [constants* of (G′, G′′) versus (frequency, rad s^{-1})]

T	G′			G′′		
°C	Constant (K_1′)	Constant (x′)	R^2	Constant (K_2′′)	Constant (y′′)	R^2
0	351.03	0.127	0.997	60.12	0.312	0.999
10	323.05	0.118	0.999	40.74	0.291	0.999
20	292.46	0.104	0.998	39.88	0.283	0.998
30	274.62	0.099	0.998	35.03	0.269	0.999
40	263.76	0.093	0.998	28.31	0.257	0.997
50	216.24	0.080	0.998	26.18	0.256	0.996

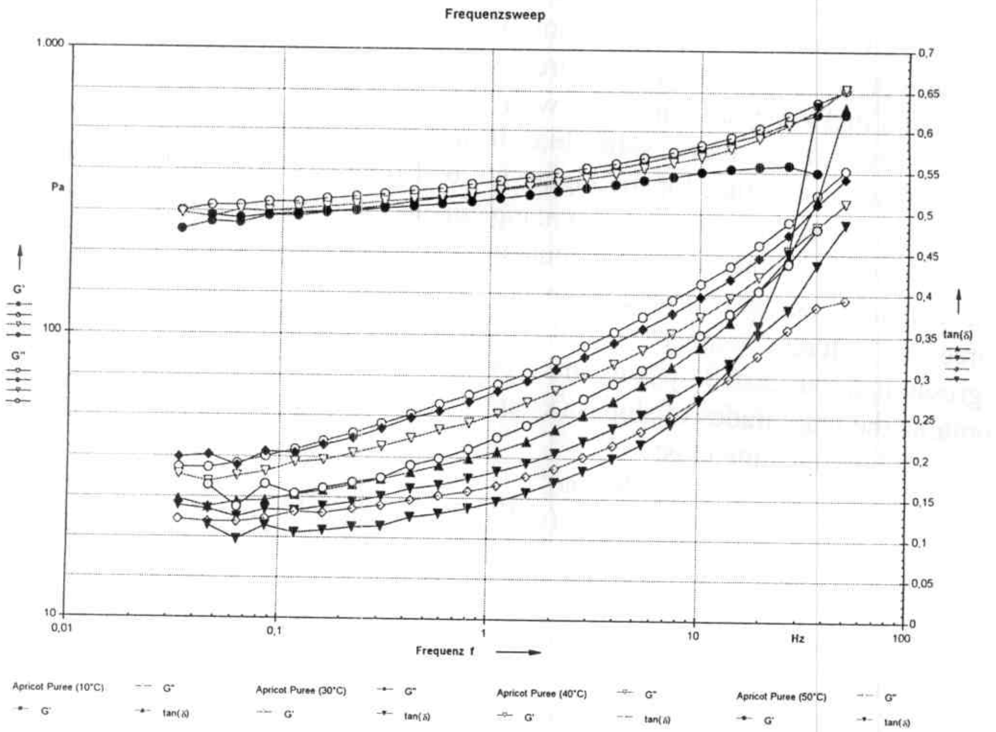


Fig. 5.48 Frequency sweeps: Storage (G′) and loss (G′′) modulus for apricot puree are shown as a function of the frequency

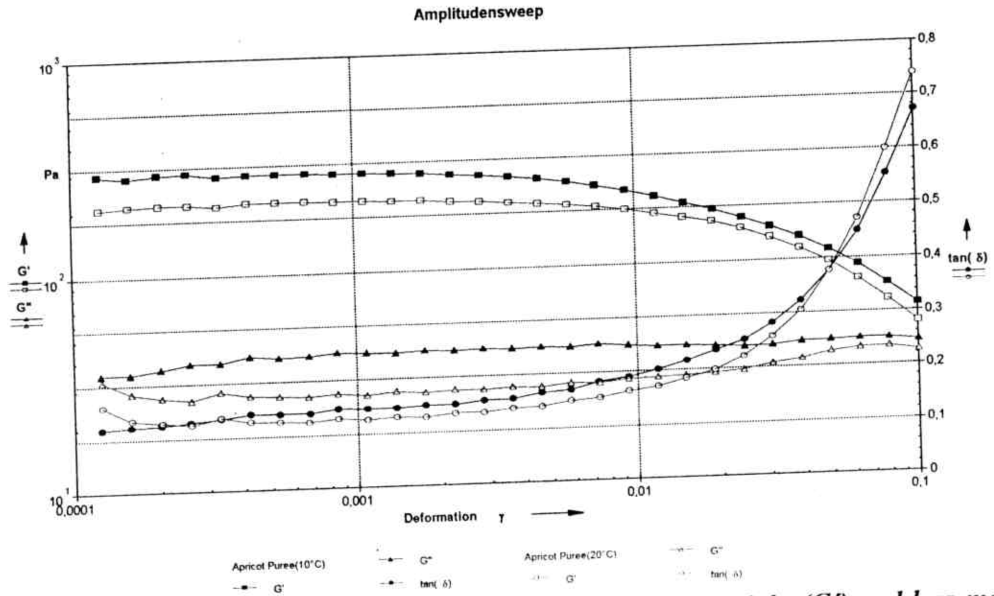


Fig. 5.49 Amplitude sweeps for apricot puree. The storage modulus(G′) and loss modulus (G′′) curves are shown as a function of the deformation (γ)

Loss angle values:

The loss angle was described by equation (4.8) as mentioned by **Kunzek (1997)**

$$\tan \delta = G''/ G' = \eta'/ \eta'' \qquad \textbf{(4.8)}$$

The loss angle for apricot puree at ω = 1 Hz were (0.227, 0.221, 0.205, 0.199, 0.189 and 0.178°) at temperatures (0, 10, 20, 30, 40 and 50 °C), respectively.

5.15. Mechanical properties of apricot fruit:

Few data on the storage of apricot in refrigerated and another conditions are available in the literature. Fruit texture, maturity, and ripeness are measured by a variety of techniques. These range from physical and chemical measurements to purely visual inspection. While many test are used, few are entirely reliable, and there is a need for better or faster testing methods. For some fruits a suitable field test has yet to be identified. For mechanical properties of fruit flesh, compression, tension, and shear tests have been used.

5.15.1 Penetration test:

Softening of the fleshy tissues of fruits is one of the most important changes occurring during storage and has a major influence on customer acceptability. As shown in Table 7.6, the apricot (*Prunus armeniaca L.,*) at the different stored conditions were about the same size, with a diameter of (5.94 - 5.19 cm). The density was 1089.86 kg/m^3, and the total solids was 16.94 %.
The mechanical parameters (Penetration test) for apricot fruit, firmness was expressed as the maximum force (N), Young's modulus (MPa), energy (the area

under loading curve by J), the energy1 (the area between the loading curve to maximum force and the deformation axis represents the total work of loading) and deformation (mm) are presented in Tables (5.47-48). Throughout storage the mechanical parameters values decreased for fruits under all conditions. Apricot stored under chilled condition showed higher in maximum force, Young's modulus, energy and energy1. While the deformation was the same in all conditions and all storage days (see Figs.5.50-51). The seam results observed by **Iwata and Kinoshita (1978)** they found the chilling condition at 0 and 5 °C were better than 10 °C nonchilling condition for storage Japanese apricot. The fruits weight and size decrease with storage time increasing, this results were in agreement with **Andrich and Fiorentini (1986).**

Table 5.47 Physico-Mechanical parameters1(Penetration test) for apricot fruits stored under nonchilled conditions

Storage time (days)	Weight gm	Diameter cm	Length cm	Maximum Force N	Young's modulus MPa	Energy J	Energy1 J
0	64.39±0.21	5.94±0.12	4.98±0.07	6.404±0.423	0.019±0.002	0.030±0.002	0.029±0.002
1	64.54±0.16	5.81±0.14	5.04±0.03	4.568±0.046	0.018±0.001	0.025±0.001	0.023±0.001
2	64.02±0.25	5.84±0.16	4.89±0.09	3.964±0.165	0.016±0.001	0.022±0.002	0.018±0.001
3	63.47±0.19	5.72±0.14	4.80±0.08	3.168±0.124	0.015±0.000	0.013±0.001	0.010±0.000
4	63.54±0.10	5.88±0.11	4.75±0.11	1.875±0.071	0.012±0.001	0.011±0.001	0.007±0.000
5	63.11±0.19	5.54±0.07	4.63±0.13	1.727±0.081	0.010±0.001	0.010±0.000	0.007±0.000
6	62.86±0.27	5.47±0.16	4.56±0.17	1.429±0.081	0.010±0.001	0.009±0.001	0.005±0.001
7	61.33±0.23	5.25±0.06	4.57±0.21	1.339±0.053	0.009±0.001	0.008±0.000	0.005±0.000
8	61.07±0.15	5.14±0.14	4.49±0.19	1.148±0.078	0.005±0.000	0.007±0.001	0.005±0.000
9	60.34±0.25	5.19±0.17	4.55±0.15	1.057±0.056	0.004±0.000	0.006±0.000	0.004±0.000

Mean values ± Standard errors
Deformation =11 mm

Table 5.48 Physico-Mechanical parameters(Penetration test) for apricot fruits stored under chilled conditions

ST	Weight	Diameter	Length	Maximum Force	Young's modulus	Energy	Energy1
(days)	gm	cm	cm	N	MPa	J	J
0	64.39±0.21	5.94±0.12	4.98±0.07	6.404 ±0.423	0.0225±0.0008	0.0304±0.0019	0.0289±0.0020
1	64.77±0.16	5.98±0.05	5.03±0.09	5.805±0.282	0.0220± 0.0014	0.0306±0.0009	0.0251±0.0009
2	64.56±0.42	5.95±0.09	4.96±0.18	5.622±0.349	0.0214±0.0023	0.0299±0.0011	0.0269±0.0017
3	64.39±0.60	5.93±0.27	4.91±0.22	4.882±0.219	0.0205±0.0007	0.0242±0.0023	0.0227±0.0018
4	64.37±0.29	5.91±0.17	4.94±0.14	4.683±0.157	0.0208±0.0007	0.0222±0.0012	0.0207±0.0012
5	64.45±0.48	5.93±0.25	4.94±0.22	4.129±0.075	0.0205±0.0006	0.0198±0.0005	0.0193±0.0006
6	64.63±0.45	5.95±0.23	4.99±0.27	4.023±0.047	0.0176±0.0011	0.0197±0.0006	0.0191±0.0007
7	64.46±0.52	5.95±0.21	4.95±0.24	3.905±0.099	0.0165±0.0013	0.0193±0.0009	0.0182±0.0008
8	64.02±0.61	5.87±0.35	4.81±0.26	3.754±0.062	0.0164±0.0007	0.0192±0.0004	0.0176±0.0006
9	63.87±0.34	5.81±0.23	4.72±0.13	3.615±0.055	0.0157±0.0011	0.019±0.0006	0.0169±0.0006
10	63.66±0.30	5.77±0.17	4.68±0.11	3.557±0.048	0.0149±0.0010	0.0186±0.0006	0.0163±0.0009
11	63.59±0.12	5.74±0.15	4.64±0.07	3.406±0.068	0.0144±0.0007	0.0187±0.0005	0.0155±0.0009
12	63.54±0.38	5.69±0.19	4.62±0.12	3.280±0.110	0.0143±0.0009	0.0167±0.0014	0.0153±0.0004
13	63.19±0.16	5.51±0.10	4.48±0.09	3.252±0.045	0.0135±0.0010	0.016±0.0007	0.0149±0.0007
14	63.24±0.36	5.53±0.24	4.47±0.13	3.238±0.024	0.0129±0.0006	0.0159±0.0005	0.0144±0.0004
15	62.99±0.51	5.42±0.26	4.39±0.20	3.211±0.087	0.0127±0.0003	0.0158±0.0007	0.0140±0.0006
16	62.78±0.17	5.44±0.09	4.53±0.08	3.167±0.068	0.0126±0.0005	0.0154±0.0006	0.0129±0.0006
17	62.67±0.24	5.45±0.14	4.50±0.09	3.056±0.089	0.0112±0.0007	0.0141±0.0006	0.0127±0.0006
18	62.06±0.35	5.32±0.19	4.34±0.12	2.844±0.085	0.0103±0.0005	0.0142±0.0005	0.0122±0.0004
19	61.89±0.42	5.28±0.27	4.31±0.15	2.703±0.085	0.0098±0.0005	0.0126±0.0004	0.0113±0.0006
20	61.55±0.53	5.22±0.29	4.29±0.18	2.720±0.053	0.0093±0.0002	0.0118±0.0005	0.0109±0.0004
21	60.97±0.47	5.19±0.36	4.28±0.11	2.232±0.080	0.0087±0.0002	0.0111±0.0008	0.0098±0.0007
22	61.09±0.30	5.14±0.18	4.26±0.09	1.791±0.122	0.0074±0.0002	0.009±0.0004	0.0081±0.0004
23	60.78±0.25	5.12±0.12	4.23±0.13	1.591±0.075	0.0070±0.0002	0.0082±0.0005	0.0076±0.0005
24	60.77±0.41	5.15±0.21	4.19±0.18	1.450±0.064	0.0065±0.0006	0.0077±0.0005	0.0070±0.0003
25	60.54±0.19	5.14±0.08	4.21±0.09	1.221±0.074	0.0044±0.0005	0.0065±0.0003	0.0053±0.0003
26	60.00±0.31	5.11±0.17	4.14±0.13	1.149±0.051	0.0039±0.0001	0.0058±0.0003	0.0053±0.0003
27	60.01±0.33	5.14±0.18	4.17±0.15	1.056±0.038	0.0037±0.0001	0.0056±0.0003	0.005±0.0002
28	60.03±0.29	5.14±0.16	4.19±0.09	1.026±0.038	0.0036±0.0001	0.0049±0.0003	0.0045±0.0003
29	59.97±0.25	5.11±0.17	4.18±0.10	0.947±0.065	0.0031±0.0003	0.0041±0.0002	0.0038±0.0003
30	59.93±0.34	5.13±0.19	4.16±0.17	0.772±0.024	0.0028±0.0001	0.0037±0.0002	0.0035±0.0002

Mean values ± Standard errors
ST (Storage time) *Deformation =11 mm*

5.15.2 Compression test:

During compression the part of the apricot in contact with the substrate deforms the most and bruises due to the rupture of cells. The bruise usually starts when isolated cell layers collapse at right angles to the direction of loading (**Khan 1989**). The collapsed bands increase in density, merging together to give an impression of a continuous hemispherical bruise.

The mechanical parameters (compression test) for apricot fruit, firmness was expressed as the maximum force (N), Young's modulus(MPa), energy (the area under loading curve by J) and the energy1 (the area between the loading curve to maximum force and the deformation axis represents the total work of loading) are presented in Tables (5.49-50). All mechanical parameters values decreased throughout storage time for apricot fruits under all conditions (see Figs.5.52-53). These parameters for apricot fruit stored at nonchilled condition were ranged from 25.23 to 5.71N ; 0.0233 to 0.0068 MPa ; 0.3062 to 0.0471 J ; 0.2494 to 0.0462 J and 13.01 to 10.61 mm for maximum force, Young's modulus, energy, energy1 and deformation, respectively. In the same time these parameters were ranged from 25.23 to 5.02 N ; 0.0233 to 0.0049 MPa ; 0.3062 to 0.0348 J ; 0.2494 to 0.0319 J and 13.01 to 9.66mm, for apricot fruit stored at chilled condition.

Table 5.49 Physico-Mechanical parameters(Compression test) for apricot fruits stored under nonchilled conditions

ST (days)	Weight gm	Diameter cm	Length cm	Maximum Force N	Young's modulus MPa	Energy J	Energy1 J	Deformation mm
0	64.79 ±0.29	5.99 ±0.07	5.06 ±0.04	25.23 ±0.24	0.0233 ±0.004	0.3062 ±0.002	0.2494 ±0.009	13.01 ±0.16
1	64.73 ±0.21	5.95 ±0.10	5.07 ±0.09	22.81 ±0.25	0.0196 ±0.006	0.2659 ±0.009	0.1909 ±0.008	12.66 ±0.11
2	64.35 ±0.21	5.89 ±0.10	4.90 ±0.05	19.03 ±0.25	0.0185 ±0.002	0.2100 ±0.002	0.1695 ±0.004	12.57 ±0.14
3	63.68 ±0.32	5.76 ±0.08	4.83 ±0.12	16.72 ±0.17	0.0132 ±0.007	0.1811 ±0.005	0.1402 ±0.001	12.03 ±0.08
4	63.39 ±0.24	5.74 ±0.11	4.79 ±0.14	14.68 ±0.12	0.0129 ±0.009	0.1246 ±0.001	0.0989 ±0.007	11.85 ±0.11
5	63.17 ±0.15	5.62 ±0.08	4.68 ±0.14	11.58 ±0.25	0.0113 ±0.003	0.0973 ±0.006	0.0872 ±0.006	11.10 ±0.22
6	62.91 ±0.23	5.52 ±0.05	4.60 ±0.12	9.52 ±0.09	0.0085 ±0.004	0.0748 ±0.003	0.0676 ±0.003	11.11 ±0.05
7	61.75 ±0.26	5.34 ±0.09	4.46 ±0.17	8.38 ±0.15	0.0077 ±0.002	0.0669 ±0.009	0.0624 ±0.004	11.02 ±0.34
8	61.28 ±0.22	5.21 ±0.08	4.46 ±0.15	6.10 ±0.27	0.0075 ±0.008	0.0516 ±0.001	0.0509 ±0.009	11.03 ±0.07
9	60.57 ±0.20	5.22 ±0.11	4.45 ±0.10	5.71 ±0.14	0.0068 ±0.005	0.0471 ±0.008	0.0462 ±0.006	10.61 ±0.09

Mean values ± Standard errors

Table 5.50 Physico-Mechanical parameters (Compression test) for apricot fruits stored under chilled conditions

Storage time	Weight	Diameter	Length	Maximum Force	Young's modulus	Energy	Energy1	Defor-mation
(days)	gm	cm	cm	N	MPa	J	J	mm
0	64.79 ±0.29	5.99 ±0.07	5.06 ±0.04	25.23 ±0.24	0.0233 ±0.004	0.3062 ±0.002	0.2494 ±0.009	13.01 ±0.16
1	64.78 ±0.20	5.97 ±0.33	5.09 ±0.12	24.89 ±0.31	0.0219 ±0.005	0.3010 ±0.008	0.2153 ±0.004	14.30 ±0.34
2	64.76 ±0.39	5.97 ±0.31	5.06 ±0.27	24.02 ±0.57	0.0211 ±0.002	0.2743 ±0.008	0.1997 ±0.007	14.55 ±0.38
3	64.64 ±0.52	5.91 ±0.36	5.01 ±0.18	23.47 ±0.48	0.0201 ±0.004	0.2728 ±0.001	0.1950 ±0.002	15.34 ±0.41
4	64.44 ±0.37	5.92 ±0.24	4.97 ±0.31	22.38 ±0.32	0.0199 ±0.009	0.2631 ±0.006	0.1937 ±0.004	15.04 ±0.27
5	64.41 ±0.30	5.90 ±0.21	4.95 ±0.18	21.49 ±0.41	0.0196 ±0.002	0.2535 ±0.007	0.1846 ±0.000	14.98 ±0.24
6	64.43 ±0.32	5.90 ±0.20	4.96 ±0.21	20.42 ±0.36	0.0190 ±0.001	0.2399 ±0.003	0.1823 ±0.003	14.98 ±0.36
7	64.28 ±0.31	5.87 ±0.24	4.93 ±0.20	19.05 ±0.51	0.0185 ±0.005	0.2247 ±0.001	0.1809 ±0.004	14.88 ±0.39
8	64.14 ±0.43	5.84 ±0.12	4.87 ±0.09	18.30 ±0.48	0.0175 ±0.006	0.2108 ±0.001	0.1811 ±0.005	13.44 ±0.45
9	63.92 ±0.51	5.86 ±0.42	4.74 ±0.11	17.79 ±0.33	0.0170 ±0.005	0.2062 ±0.004	0.1830 ±0.009	13.25 ±0.26
10	63.62 ±0.47	5.79 ±0.23	4.65 ±0.24	17.35 ±0.36	0.0166 ±0.004	0.1971 ±0.005	0.1794 ±0.003	12.92 ±0.37
11	63.56 ±0.55	5.78 ±0.36	4.62 ±0.19	16.05 ±0.47	0.0150 ±0.002	0.1816 ±0.002	0.1795 ±0.004	12.64 ±0.32
12	63.37 ±0.29	5.63 ±0.25	4.56 ±0.08	15.81 ±0.28	0.0149 ±0.002	0.1662 ±0.009	0.1606 ±0.001	12.19 ±0.22
13	63.24 ±0.41	5.58 ±0.37	4.49 ±0.11	15.18 ±0.32	0.0144 ±0.003	0.1590 ±0.007	0.1507 ±0.005	12.10 ±0.19
14	63.25 ±0.53	5.59 ±0.39	4.50 ±0.17	14.45 ±0.45	0.0139 ±0.004	0.1568 ±0.001	0.1490 ±0.009	11.95 ±0.26
15	63.05 ±0.51	5.46 ±0.21	4.37 ±0.25	14.28 ±0.47	0.0126 ±0.006	0.1386 ±0.008	0.1303 ±0.003	11.56 ±0.32

Mean values ± Standard errors

Table 5.50 Continuous Physico-Mechanical parameters (Compression test) for apricot fruits stored under chilled conditions

Storage time (days)	Weight gm	Diameter cm	Length cm	Maximum Force N	Young's modulus MPa	Energy J	Energy1 J	Deformation mm
16	62.84 ±0.43	5.43 ±0.36	4.41 ±0.12	13.14 ±0.38	0.0123 ±0.003	0.1243 ±0.006	0.1198 ±0.007	11.11 ±0.18
17	62.62 ±0.32	5.41 ±0.18	4.43 ±0.17	12.62 ±0.36	0.0122 ±0.007	0.1155 ±0.001	0.1068 ±0.005	11.18 ±0.31
18	62.21 ±0.47	5.40 ±0.31	4.35 ±0.16	12.45 ±0.51	0.0119 ±0.002	0.1013 ±0.003	0.0915 ±0.009	11.03 ±0.15
19	61.90 ±0.56	5.33 ±0.29	4.30 ±0.24	12.09 ±0.48	0.0114 ±0.001	0.0928 ±0.001	0.0846 ±0.008	11.03 ±0.24
20	61.74 ±0.45	5.28 ±0.22	4.26 ±0.23	11.60 ±0.26	0.0110 ±0.005	0.0847 ±0.001	0.0759 ±0.007	10.96 ±0.20
21	61.12 ±0.45	5.21 ±0.31	4.27 ±0.21	10.90 ±0.38	0.0108 ±0.003	0.0801 ±0.004	0.0725 ±0.004	10.91 ±0.27
22	60.92 ±0.38	5.18 ±0.21	4.27 ±0.17	10.10 ±0.42	0.0104 ±0.001	0.0759 ±0.007	0.0706 ±0.001	10.65 ±0.19
23	60.92 ±0.53	5.22 ±0.34	4.25 ±0.16	9.97 ±0.36	0.0103 ±0.001	0.0673 ±0.003	0.0601 ±0.008	10.56 ±0.13
24	60.72 ±0.41	5.23 ±0.24	4.22 ±0.23	9.77 ±0.25	0.0099 ±0.001	0.0617 ±0.001	0.0541 ±0.004	10.51 ±0.35
25	60.39 ±0.26	5.19 ±0.12	4.23 ±0.21	8.96 ±0.23	0.0093 ±0.002	0.0571 ±0.009	0.0503 ±0.007	10.39 ±0.28
26	60.13 ±0.38	5.17 ±0.15	4.19 ±0.18	8.09 ±0.18	0.0085 ±0.001	0.0575 ±0.005	0.0488 ±0.002	10.45 ±0.24
27	60.06 ±0.50	5.16 ±0.30	4.20 ±0.22	7.24 ±0.17	0.0077 ±0.004	0.0475 ±0.005	0.0411 ±0.004	9.73 ±0.17
28	60.08 ±0.44	5.17 ±0.36	4.18 ±0.07	6.66 ±0.14	0.0064 ±0.007	0.0464 ±0.002	0.0395 ±0.008	9.51 ±0.22
29	59.93 ±0.32	5.14 ±0.11	4.16 ±0.18	6.39 ±0.21	0.0055 ±0.001	0.0425 ±0.009	0.0388 ±0.004	9.52 ±0.25
30	60.02 ±0.21	5.13 ±0.16	4.19 ±0.08	5.02 ±0.16	0.0049 ±0.001	0.0348 ±0.007	0.0319 ±0.002	9.66 ±0.19

Mean values ± Standard errors

Effect of storage at different temperatures on mechanical properties of apricot fruit:

All the experimental data (Tables 5.47-50) have been correlated to the storage time. And also in Figs.5.50-55. From the results obtained, the following regression equations were proposed, it indicate that though the storage temperature shows a clear effect on storage period. The mechanical parameter which are probably the most important from the customer's viewpoint, increases moderately during the stored of apricot.

Table 5.51 Equation describing the relationship between the storage days and mechanical properties of apricot fruits storage at different conditions

Equ.-Nr.	Equ.	R^2
	Penetration test and non chilled storage conditions	
5.13	Weight = (-0.463 * Storage days) + 64.95	0.918
5.14	Maximum force = (-0.549 * Storage days) +5.138	0.851
5.15	Young's modulus = (-0.0017 * Storage days) +0.0194	0.978
5.16	Energy = (-0.0026 * Storage days) +0.0257	0.854
5.17	Energy1 = (-0.0026 * Storage days) +0.0231	0.797
	Penetration test and chilled storage conditions	
5.18	Weight = (-0.4707 * Storage days) + 65.18	0.959
5.19	Maximum force = (-0.1607 * Storage days) +5.459	0.949
5.20	Young's modulus = (-0.0007 * Storage days) +0.0225	0.990
5.21	Energy = (-0.0008 * Storage days) +0.0274	0.951
5.22	Energy1 = (-0.0007* Storage days) +0.0249	0.966
	Compression test and non chilled storage conditions	
5.23	Weight = (-0.1847 * Storage days) + 65.32	0.957
5.24	Maximum force = (-2.2461 * Storage days) +24.083	0.978
5.25	Young's modulus = (-0.0018 * Storage days) +0. 0212	0.927
5.26	Energy = (-0.0297 * Storage days) +0.276	0.929
5.27	Energy1 = (-0.0217* Storage days) +0.2138	0.915
5.28	Deformation = (-0.2683 * Storage days) +12.906	0.938
	Compression test and chilled storage conditions	
5.29	Weight = (-0.187 * Storage days) + 65.40	0.971
5.30	Maximum force = (-0.6425 * Storage days) +24.32	0.986
5.31	Young's modulus = (-0.0006 * Storage days) +0.0221	0.985
5.32	Energy = (-0.0094 * Storage days) +0.2911	0.977
5.33	Energy1 = (-0.0070* Storage days) +0.2309	0.966
5.34	Deformation = (0.1924 * Storage days) +14.961	0.884

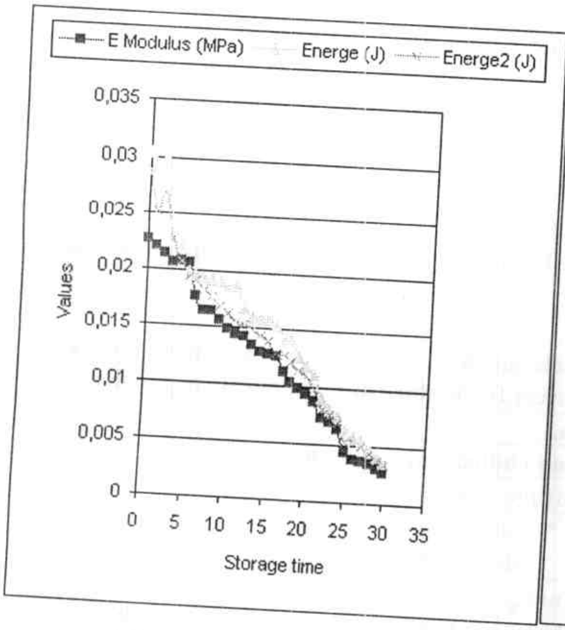


Fig. 5.50 Penetration test for apricot fruits stored at chilled conditions

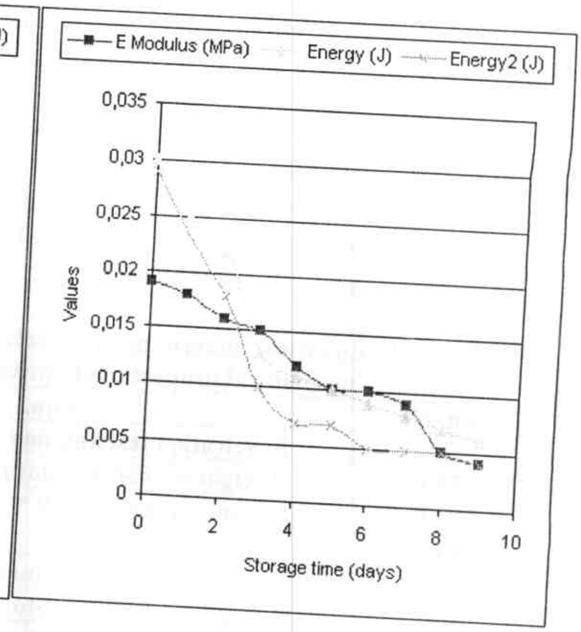


Fig. 5.51 Penetration test for apricot fruits stored at nonchilled conditions

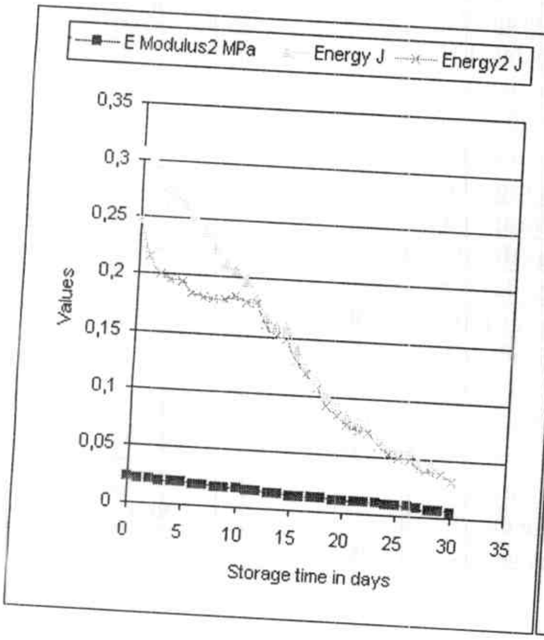


Fig. 5.52 Compression test for apricot fruits stored at chilled conditions

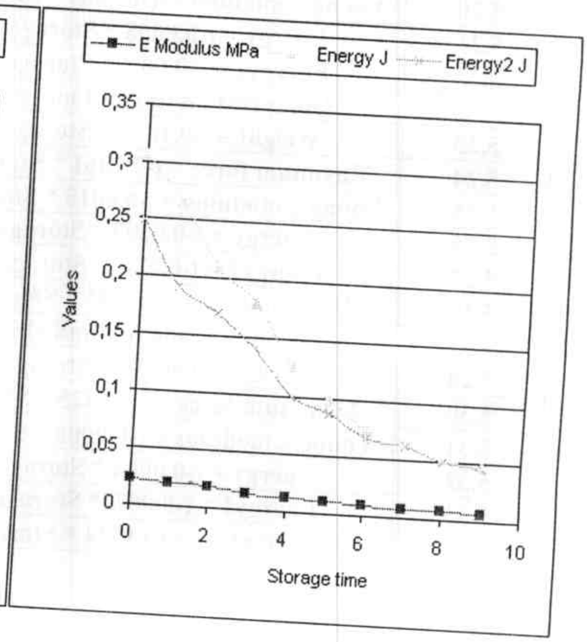


Fig. 5.53 Compression test for apricot fruits stored at nonchilled conditions

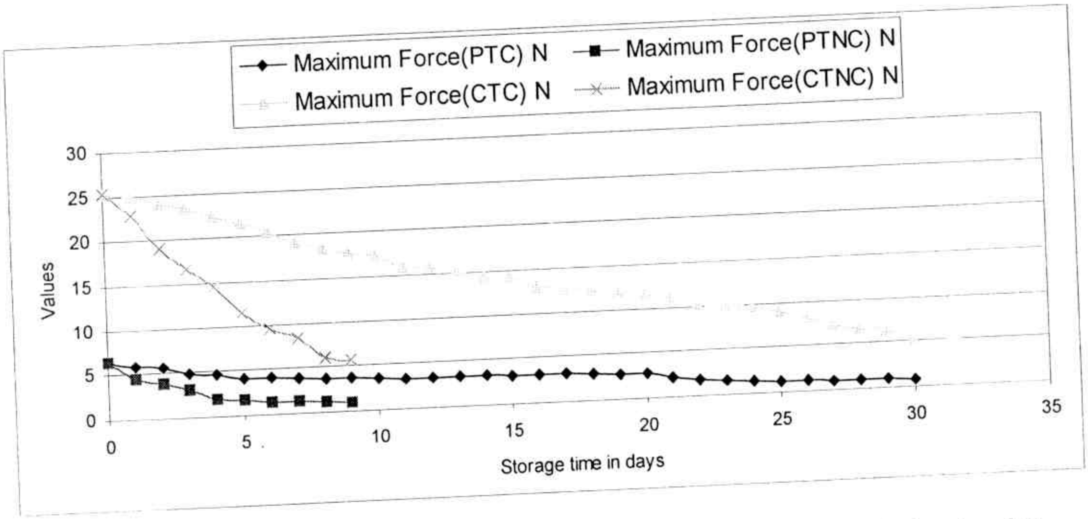


Fig. 5.54 Maximum force for Compression and Penetration tests for apricot fruits stored at chilled and nonchilled conditions .

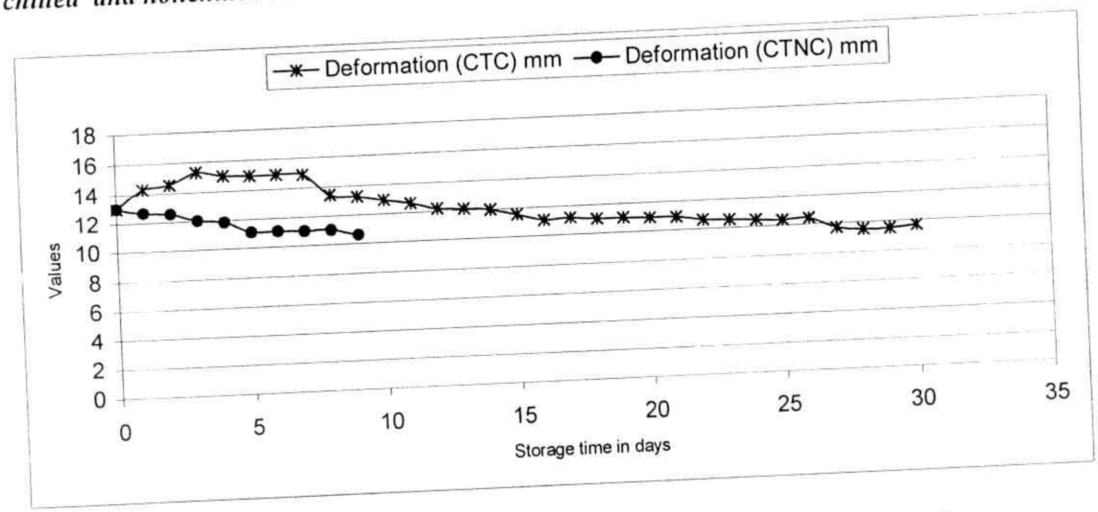


Fig. 5.55 Deformation for Compression test for apricot fruits stored at chilled and nonchilled conditions .