VISCOSITY AND QUALITY OF TOMATO JUICE AS AFFECTED BY PROCESSING METHODS

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ABSTRACT

Quality and viscosity of tomato juice is strongly governed by mechanical and thermal abuse during processing. The effect of processing and storage duration on the viscosity and quality parameters of tomato juice was evaluated in the present work. Tomato juice was obtained by two different methods, normal method (NM) and variable method (VM), and was heated by both conventional and microwave hot break treatments. Tomato juice was evaluated for various quality characteristics including precipitate weight ratio, degree of serum separation (DOSS), Brookfield viscosity, lycopene levels, vitamin C, phenols and antioxidant activity. Changes observed in several quality parameters during storage were statistically insignificant. The methods and processing had the greatest contribution toward viscosity, whereas storage duration had no significant effects. Viscosity parameters viz precipitate weight, DOSS and Bostwick consistency revealed that juice processed by VM was more viscous than that of NM, irrespective of the hot break processing used. Ascorbic acid and lycopene content varied significantly with mechanical methods and processing conditions. However, phenolic content and antioxidant activity remained stable. The variable process represents an improvement over the conventional by enabling tomato processors to improve the consistency of the tomato product.

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PRACTICAL APPLICATIONS

Quartering or slicing tomatoes followed by hot break processing techniques can significantly improve the quality of tomato juice in terms of reduced degree of serum separation and precipitate weight ratio. The modified technology could be considered as a viable and economical method for small- and medium-scale tomato processors with limited resources and facilities at their disposal.

INTRODUCTION

Tomato is a widely processed vegetable to be used as a vital ingredient in many products, soups, sauces and ketchups. Growth of fast foods such as pizzas, burgers and French fries, which are often served with tomato sauce and tomato salsa, has further given fresh impetus to the tomato processing industry. Grades of tomato juice are largely determined by its color, viscosity, flavor and soluble solids content (Barett *et al.* 1998). Viscosity is undoubtedly an important quality attribute of tomato products arising from the retention of pectin and destruction of pectin methyl esterase and polygalactouronase during hot break treatment. Inactivation of pectolytic enzymes by heat results in significantly higher values of serum and efflux viscosity (Hayes *et al.* 1998). Tomato processors generally crush tomatoes, prior to hot breaking to realize higher juice yields. Crushing of tomatoes prior to hot breaking often leads to more serious fragmentation and disruption of cell walls, quick liberation of pectolytic enzymes as well as pectin from cell walls. This makes pectin more vulnerable to attack by pectolytic enzymes, resulting in rapid degradation of pectin. Under commercial practice too, 100% retention of pectic substances is never possible under best practical commercial conditions of rapid heating of crushed tomatoes (Miers *et al.* 1967). The time gap that elapses between crushing and hot breaking is also a crucial factor determining the degree of pectin destruction. The lower the time gap, the higher the retention of pectin and the higher is the viscosity. Understanding the fact that minimizing cellular destruction of tomatoes prior to hot breaking can save losses to pectin, an experiment was designed to investigate the effect of mechanical methods such as crushing vis-à-vis quartering, hot break processing and storage period on quality of tomato juice.

MATERIALS AND METHODS

Preparation of Experimental Material

Red and firm tomatoes (variety AR 5656, Bernadine) of uniform size and shape were selected for the study. The fruits were washed in a water tank to remove surface microflora and dirt adhering to the fruits. One kilogram of tomatoes was taken for each treatment, and the experiment was repeated thrice on two consecutive days. In the first treatment, the tomatoes were crushed (normal method [NM]) in a laboratory scale crusher (Johnston Automation Co., New Delhi, India) and the contents collected in a stainless steel vessel. The crushed mass was divided into two lots and subjected to a hot break treatment by conventional and microwave methods. In the conventional hot break treatment, the contents were heated in a stainless steel vessel, on a domestic stove top, until the temperature reached 90C (come-up time ~4 min) and thereafter, were held for 2 min. In the microwave/hot break treatment, the crushed mass was heated in a microwave (domestic microwave BPL, BMO700T, BPL India, Noida, India; 5-L capacity; power output 1,200 W; frequency 2,450 MHz). Heating was carried out at full power for 4 min followed by heating at half power for an additional 4 min in a glass dish covered with plastic film. For each hot break processing, consecutive five batches (each comprising 1 kg of crushed tomato) were heated and combined together. The combined tomato mass was sieved through a screen (size of 0.84 mm) to remove skin and seeds to recover tomato juice. The juice, thus obtained, was heat processed (90C) for 1 min, poured hot in glass bottles and cooled under room temperature (35 ± 2C). In the second treatment, the tomatoes were quartered into four pieces (variable method [VM]) and were subjected to similar hot break treatment by conventional/microwave method and heat processed as described earlier. The juice bottles were stored in cold storage (7–10C) for a period of 6 months.

Viscosity Analysis

Precipitate weight ratio, serum separation and Bostwick consistency were taken as parameters for evaluating viscosity. Precipitate weight ratio expressed as percentage was determined by taking the weight ratio of precipitate to the initial sample weight, after centrifugation of a known weight of sample (Takada and Nelson 1983). Serum separation in the processed samples was determined by using a modified method of Caradec and Nelson (1985). Bostwick consistency determinations were made using Bostwick consistometer measuring the distance that the juice front traveled in 30 s at 20C. Triplicate measurements were performed for each sample.

Quality Analysis

Percent soluble solids was measured using Abbe's refractometer. Titratable acidity, expressed as milligrams of citric acid per gram of sample, was determined by a fixed endpoint titration (pH 8.1) against 0.1 N NaOH. All measurements were made in triplicate. Lycopene, from tomato products, was extracted with hexane : methanol : acetone (2:1:1) mixture containing 2.5% butylated hydroxytoluene. Absorbance of the hexane extract was measured using a UV-VIS spectrophotometer at 502 nm against a hexane blank. Concentration of lycopene was calculated using the extinction coefficient (*E*%) of 3,150 (Ranganna 1976). Results were expressed as mg/100 g fresh weight basis (FWB). Ascorbic acid content was determined by the method as described by Albrecht (1993), titrating a known weight of sample against 2,6-dichlorophenol-indophenol dye using 3% metaphosphoric acid as extracting medium. Results were expressed as mg/100 g FWB. Total phenols were determined using the Folin–Ciocalteau reagent (Singleton and Rossi 1965). Results were expressed as mg/100 g FWB with catechol as standard. Antioxidant activity was measured using the ferric reducing antioxidant power (FRAP) assay of Benzie and Strain (1996). The FRAP reagent consisted of 10-mM 2,4,6-tripyridyl-S-triazine in 40-mM HCl, 20-mM ferric chloride and 300 mM sodium acetate buffer, pH 3.6 in the ratio of 1:1:10 (v/v). A 100-µL extract was added to 3 mL of FRAP reagent and mixed thoroughly. After standing at ambient temperature (30C) for 4 min, absorbance at 593 nm was noted against a reagent blank. Calibration was against a standard curve (50- to 1,000-µM ferrous ion) produced by the addition of freshly prepared ammonium ferrous sulphate. Values were obtained from three replicates and expressed as µmol FRAP/g FWB.

Statistical Analysis

Analysis of variance (ANOVA) was performed to determine the significance of the three factors, namely, methods, processing and storage duration along with their interactions. Data were analyzed using SPSS 13.0 software (SPSS, New Delhi, India).

RESULTS AND DISCUSSION

Viscosity Parameters

Degree of Serum Separation (DOSS). The effect of different methods, normal and variable and hot break processing techniques on viscosity parameters and on the quality of tomato juice are presented in Figs. 1–7. *F* ratio and its significance for various factors along with their interaction are presented in Table 1. DOSS is a useful method of evaluating viscosity, for quality control purposes, used by the tomato processing industry. Mechanical methods and subsequent hot break processing, by conventional and microwave methods affected DOSS significantly. ANOVA indicates that there were significant

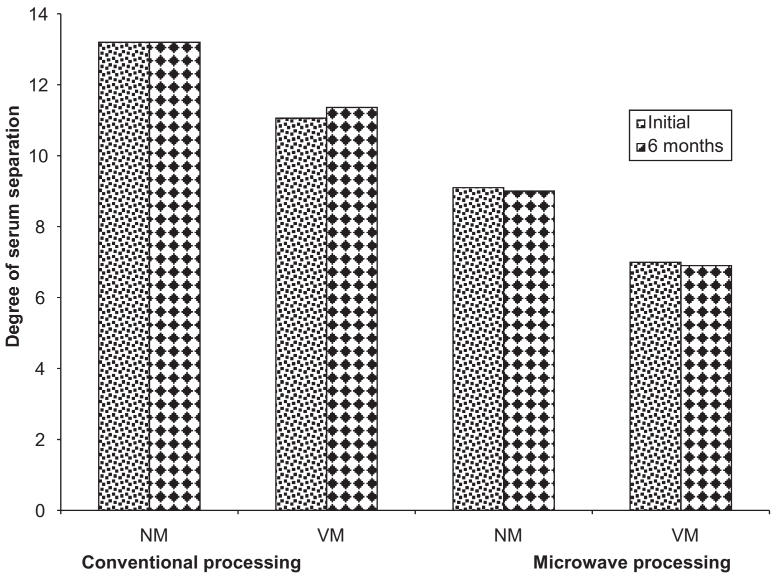

FIG. 1. EFFECT OF PROCESSING METHODS ON DEGREE OF SERUM SEPARATION OF TOMATO JUICE

Data are the average of three measurements. NM and VM represent normal and variable methods, respectively.

effects of methods and hot break processing on DOSS, but their interactions were not significant. Among the methods, DOSS was found to be lowest in the tomato juice obtained by the VM method irrespective of the hot break processing used. The mean values under conventional processing were 16.00 mL for control, 13.20 mL for NM and 11.06 mL for VM. Similarly, under microwave processing, the mean values were 9.1 mL for NM and 7.10 mL for VM. Considering the fact that under commercial conditions tomatoes are being processed into juice by crushing and then subjected to conventional hot break processing, use of VM followed by microwave hot break can bring about substantial reduction (~47%) in DOSS. Differences in DOSS, as obtained under different methods, can be attributed to two factors, namely, the amount of soluble pectin retained and microstructural differences in cellular debris. The crushed mass of processed tomatoes consists of disintegrated cells of pericarp and pulp mixed with clear serum. Crushing of tomatoes, as in NM, results in severe fragmentation and cellular disruption. Extensive shredding also leads to change in the shape of cells, the resultant cell wall being nonlinear, having coarse cell walls. This, accompanied with low pectin retention, can lead to high DOSS. In contrast, quartering or slicing of tomatoes does not

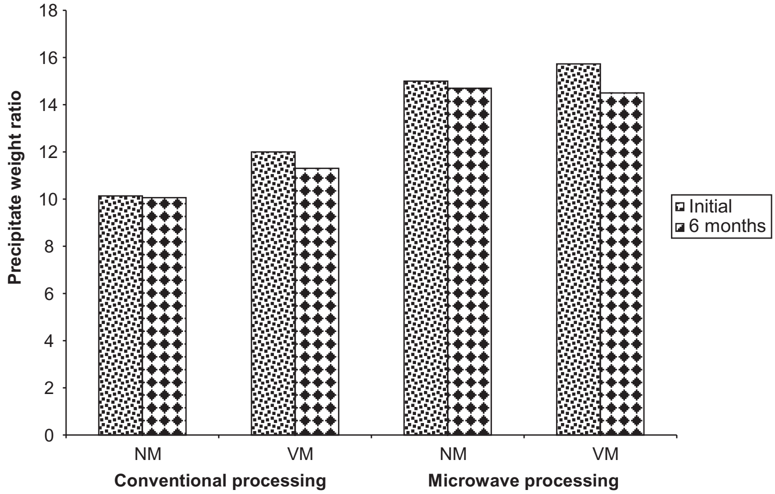

FIG. 2. EFFECT OF PROCESSING METHODS ON PRECIPITATE WEIGHT RATIO OF TOMATO JUICE

Data are the average of three measurements. NM and VM represent normal and variable methods, respectively.

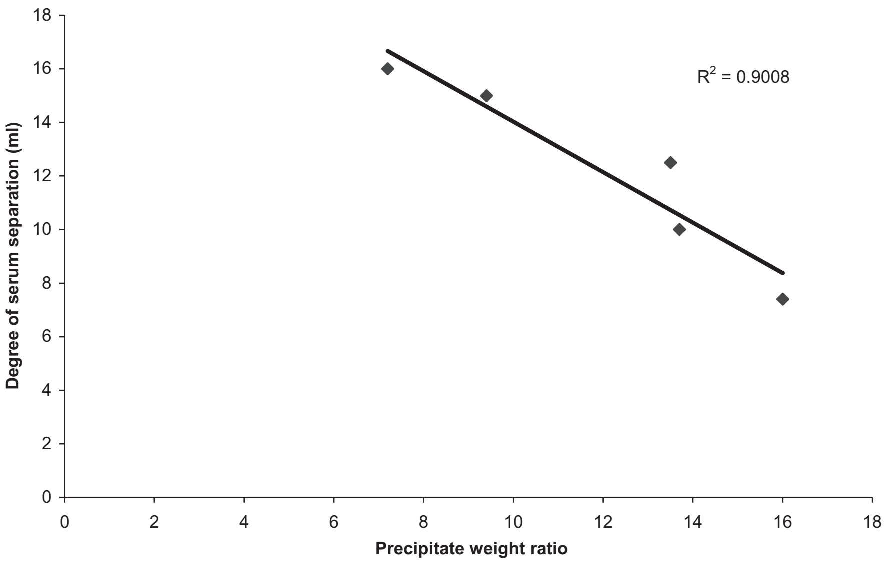

FIG. 3. CORRELATION BETWEEN PRECIPITATE WEIGHT RATIO AND DEGREE OF SERUM SEPARATION OF TOMATO JUICE

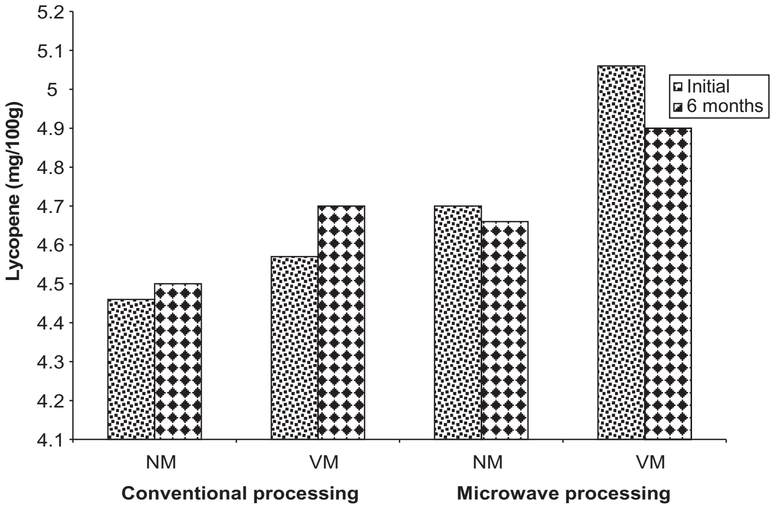

FIG. 4. EFFECT OF PROCESSING METHODS ON LYCOPENE CONTENT OF TOMATO JUICE

Data are the average of three measurements, and error bars represent SD. NM and VM represent normal and variable methods, respectively.

involve any shredding or serious fragmentation of cell walls, resulting in slow release of pectolytic enzymes which are inactivated by the subsequent hot breaking, leading to better retention of pectin and low DOSS. Further, more low DOSS as obtained under microwave processing can be attributed to faster inactivation of enzymes.

Tomato consistency is an interplay between two factors, the nature of cellulosic wall materials and retention of pectic substances (Whitten Berger and Nutting 1957). The presence of pectic substances outside the cells, as sticky, charged and adhesive surface, may result in an increase in hydrodynamic volume and thereby consistency. Pectin seems to have coated the collapsed cell wall, perhaps allowing for water binding and improved consistency (Rha 1978). Both disrupted cell structures, along with soluble pectin, are required to achieve high viscosity (Xu *et al.* 1986). There was no apparent change in DOSS with respect to storage period, indicating its high stability over storage.

Precipitate Weight Ratio. The precipitate weight ratio refers to the quantity of water insoluble solids (WIS) and its physical properties (Takada and Nelson 1983). WIS primarily represent the high molecular weight cell walls and middle lamella components or pectates that are important determinants of consistency (Thakur *et al.* 1996). Tomato cultivars, maturity, breaking temperature, pulping conditions mainly affect the quantity of WIS solids and

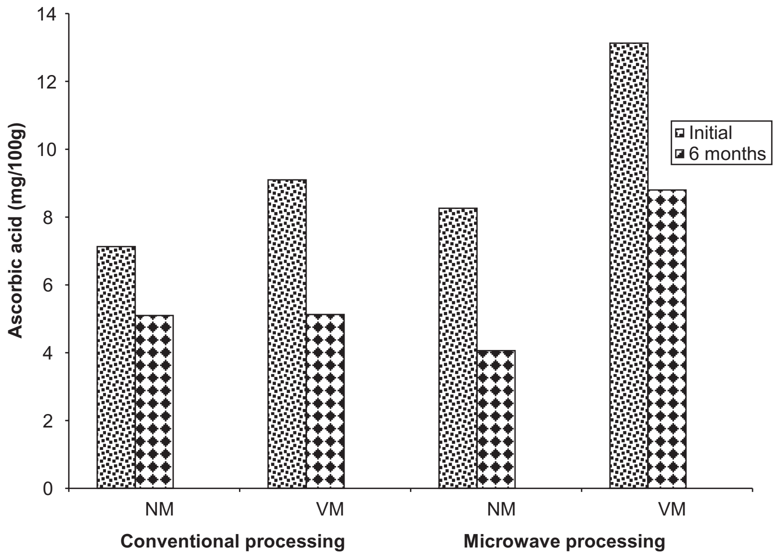

FIG. 5. EFFECT OF PROCESSING METHODS ON ASCORBIC ACID CONTENT OF TOMATO JUICE
Data are the average of three measurements, and error bars represent SD. NM and VM represent normal and variable methods, respectively.

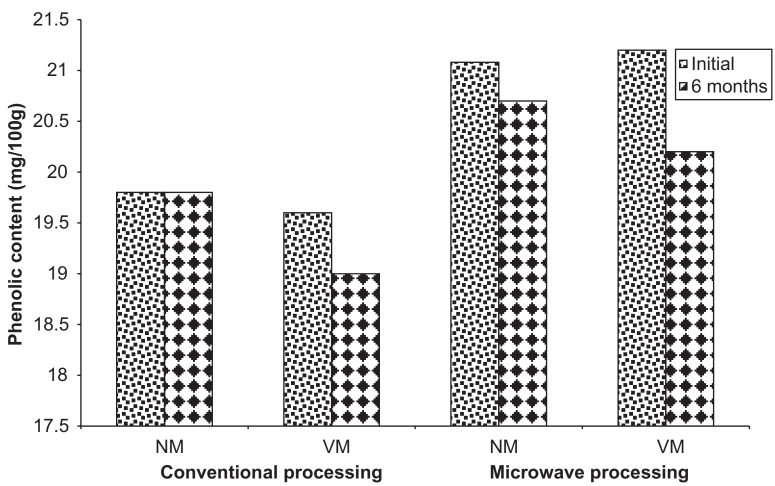

FIG. 6. EFFECT OF PROCESSING METHODS ON PHENOLICS
Data are the average of three measurements, and error bars represent SD. NM and VM represent normal and variable methods, respectively.

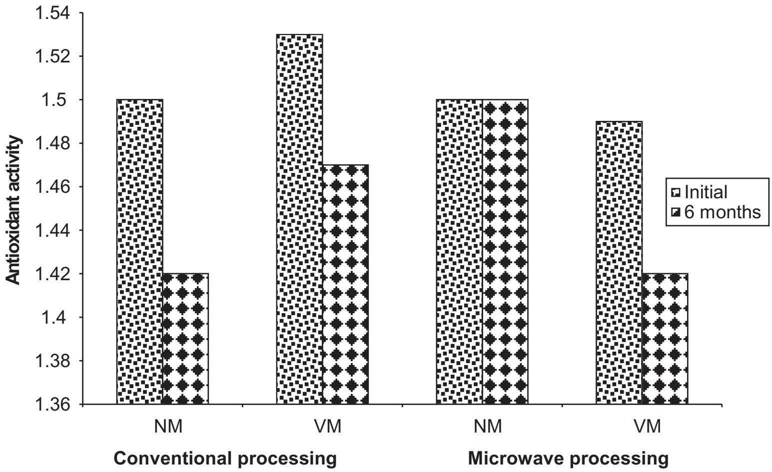

FIG. 7. EFFECT OF PROCESSING METHODS ON ANTIOXIDANT ACTIVITY
Data are the average of three measurements, and error bars represent SD. NM and VM represent normal and variable methods, respectively.

hence disturb the precipitate weight ratio in tomato products. The effect of two different methods and hot break processing techniques on the precipitate weight ratio of tomato juice is presented in Fig. 2. The mean values of precipitate weight ratio were highest under microwave hot breaking (NM, 15.00; VM, 15.73) followed by conventional hot breaking (NM, 10.33; VM, 12.00). Here again, we find that method, hot break processing as well interaction between method and hot breaking had significant effects (Table 1). The effects of storage duration, however, were statistically insignificant. Comparing the effects of NM and conventional hot break processing, with VM and microwave hot break, we find that there is an appreciable increase in the precipitate ratio (~54%). This indicates that a slight change in variables such as methods, crushing and quartering can result in marked improvement in viscosity.

The WIS in tomato products comprise intact cells, broken or crushed cells, long-chain polymers of lignin, cellulose, hemicelluloses and water insoluble pectic substances. High pectin retention and high retention of higher WIS, as seen under VM, may have accounted for the observed high precipitate weight ratio. Our results are in conformity with Sanchez *et al.* (2003), who have recently confirmed the importance of high WIS on rheological parameters and higher viscosity in tomato products.

A high, although inverse correlation ($r^2 = 0.9$), was found between precipitate weight and DOSS. Similar observations were made by Thakur *et al.* (1996) (Fig. 3).

TABLE 1
ANALYSIS OF VARIANCE RESULTS FOR THE DIFFERENT RESPONSES GIVING *F* VALUE AND SIGNIFICANCE

Effects Response	*F* ratio and its significance														
	M		P		T		$M \times P$		$M \times T$		$P \times T$		$M \times P \times T$		MSE
	F	Sig	*F*	Sig	*F*	Sig	*F*	Sig	*F*	Sig	*F*	Sig	*F*	Sig	
DOSS	830.39	0.00	198.72	0.00	0.003	0.96	0.029	0.867	0.542	0.472	0.388	0.54	0.388	0.54	0.13
PPT	3,280.21	0.00	149.81	0.00	69.120	0.0	85.33	0.00	9.01	0.008	25.81	0.00	0.48	0.5	0.031
Ascorbic acid	251.17	0.00	555.52	0.00	872.00	0.00	238.46	0.00	26.50	0.00	17.63	0.001	13.38	0.002	0.091
Lycopene	39.24	0.00	22.64	0.00	0.211	0.65	1.70	0.21	5.27	0.64	0.08	0.928	1.02	0.33	0.012
Phenolics	417.32	0.10	25.0	0.04	329.16	0.0	2.46	0.14	1.00	0.33	0.51	0.48	7.37	0.015	0.02
Antioxidant activity	1.65	0.22	0.87	0.37	47.52	0.0	3.94	0.06	3.50	0.08	0.12	0.731	0.05	0.81	0.001

M, method; P, hot break processing; T, storage period; $M \times P$, $M \times T$, $P \times T$, $M \times P \times T$, interaction between method, processing and storage period; MSE, mean square error; DOSS, degree of serum separation; PPT, precipitate weight ratio; sig, significance.

The viscosity of different tomato juices was also confirmed by Bostwick consistometer. The Bostwick consistometer measures the consistency of a viscous material by determining how far the material flows under its own weight along a sloped surface in a given period of time. Results reveal that methods and hot break were significant factors in determining the viscosity of tomato juice. As expected, viscosity of tomato juice processed by VM was more viscous than NM. Mean values for both hot break processing methods were the same: 13.0 ± 1.50 and 25.0 ± 2.5 cP for normal and VM, respectively (data not shown).

Quality Attributes

Total soluble solids, titrable acidity and pH of tomato juice were 4.84, 4.39 and 0.45%, respectively. The values did not change with either methods or processing techniques. Lycopene content was, however, significantly affected by the methods and processing, but the interaction between them was not significant. (Fig 4). The lycopene content in the control sample was 5 mg/100 g and ranged from 4.46 to 5.06 mg/100 g in different processed juices. Variations in values of lycopene could be due to differences in methods and processing techniques used or could be due to analytical handling procedures, which may not be practically relevant. Slightly higher values, as obtained under microwave, could have been due to increased extractability under microwaves. Crushing of tomatoes results in high fragmentation of the microfibrillar system. Reduction in particle size probably exposes lycopene to higher oxidation and chemical isomerization (Tamburini *et al.* 1999). Our results are in conformity with the results of Takeoka *et al.* (2001). Lycopene in tomato is resistant to degradation and other constituents such as ascorbic acid, and phenols may help to stabilize lycopene during processing. Overall, results indicate substantial stability of lycopene to different processing methods and storage durations.

Ascorbic Acid. The effect of different methods and processing techniques on ascorbic acid retention is shown in Fig. 5. ANOVA indicates that ascorbic acid retention was significantly affected by methods, processing techniques and their interactions. Among the methods, high values were observed in tomato juice processed by VM as against NM irrespective of heating methods used (Table 1). Fresh tomatoes are moderate sources of ascorbic acid with a mean content of 13.50 mg/100 g FWB. The content was found to decline with processing. Mean values for tomato juice was 7.13 mg/100 g in NM and 9.1 mg/100 g in conventionally processed juice. The mean values were 8.26 mg/100 g in NM and 13.13 mg/100 g in VM processed by microwaves. Despite the loss of ascorbic acid during storage, average retention was highest in tomato juice processed by VM and microwave hot break technique. Oxidation, during processing and storage, is a key factor in the destruction of ascorbic acid (Lee *et al.* 1977; Mesic *et al.* 1993). The longer the tomato juice is held at optimum conditions for oxidation, the lower will be the retention of ascorbic acid after processing. Less destruction of ascorbic acid in microwave processing as compared with conventional methods may be attributed to lower oxidation rates. Apart from this, crushing of tomatoes favors higher cellular disruption and consequently higher oxidation. Our findings are in conformity with the results of earlier workers supporting high retention in microwave heating (Howard *et al.* 1999; Kaur *et al.* 1999). Significant interaction between methods, processing and storage duration indicates that these factors are dependent on each other.

Phenolics and Antioxidant Activity. Phenolics are important constituents in fruits and vegetables, and their quantification can give vital information relating to antioxidant functioning, food quality and potential health benefits (Kaur and Kapoor 2001) The content of free phenolics as determined by the Folin–Ciocalteau method is presented in Fig. 6. The free phenolic content, in samples of different processed juices, ranged from 19.6 to 21.08 mg/100 g FWB. The content in fresh and differentially processed juices remained nearly the same. This indicates that total phenolic content was not appreciably changed either by processing or storage duration of 6 months. Our results are in conformity with the findings of Amakura *et al.* (2000), who reported that there was no difference in phenolic content of fresh and processed berries. Antioxidant activity as measured by ferric-reducing antioxidant power in processed tomato juices was attributed to free phenolic content. The values in juice ranged from 1.42- to 1.53-µmole FRAP, at par with those in fresh unprocessed tomatoes (Fig. 7). Results reveal that antioxidant activity remained stable throughout the processing and storage duration of 6 months. High stability of phenolics and antioxidant activity during processing indicates that the healthful components of tomato juice are not altered.

CONCLUSIONS

Reduced DOSS and high precipitate weight ratio suggest the importance of crushing or quartering method and hot break processing techniques in improving and managing the viscosity-related problems in tomato products. Higher viscosity can lead to significant cost saving in terms of energy and reduction in the amount of thickeners to be used. These advantages can be accrued without modifying the existing processing parameters of hot breaking and temperature. Moreover, such a technology could be considered as a viable and economical method for small-scale tomato processors with limited resources. In this context, further investigations on raw material suitability are also required for optimization of tomato processing techniques.

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