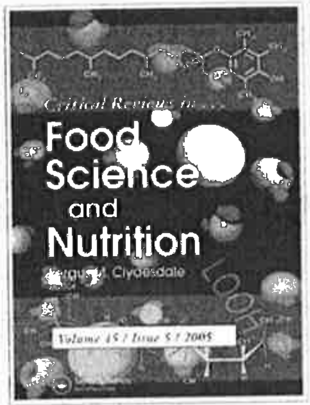

Critical Reviews in Food Science and Nutrition
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713606380

The Production and Quality of Tomato Concentrates

W. A. Hayes [a]; P. G. Smith [a]; A. E. J. Morris [a]
[a] Food Research Centre, University of Lincolnshire and Humberside, Grimsby, DN34 5AA, UK.

To cite this Article Hayes, W. A. , Smith, P. G. andMorris, A. E. J.(1998) 'The Production and Quality of Tomato Concentrates', Critical Reviews in Food Science and Nutrition, 38: 7, 537 — 564
To link to this Article: DOI: 10.1080/10408699891274309
URL: http://dx.doi.org/10.1080/10408699891274309

Critical Reviews in Food Science and Nutrition, 38(7):537–564 (1998)

The Production and Quality of Tomato Concentrates

W. A. Hayes, P. G. Smith, and A. E. J. Morris
Food Research Centre, University of Lincolnshire and Humberside, Grimsby, DN34 5AA, UK

ABSTRACT: The standards and specifications for the quality and composition of tomato concentrates are reviewed. The main quality parameters of tomato puree and paste are color, consistency and flavor. Overall, there is an absence of standardization of methods and instruments to define quality. While color can now be measured objectively, there are currently no standard color requirements for tomato concentrates. Rheological measurements on both tomato juice and concentrates are reviewed; the power law finds wide applicability, although other rheological characteristics, particularly time dependency, have received far less attention and there has been little effort to relate rheological understanding to the commonly used empirical tests such as consistency measurements. The volatiles responsible for flavor and odor have been identified to the point where the natural odor of tomato paste can be imitated. Attempts to develop objective methods as a substitute for sensory assessment are reviewed.

KEY WORDS: quality, standards, tomato, concentrates, processing, rheology.

NOMENCLATURE

a, index in Eq. 6 (–); a, Judd-Hunter redness/greenness (–); A, coefficient in Eq. 10 (Pa s); b, material specific constant in Eq. 8 (K); b, coefficient in Eq. 10 (–); C, coefficient, in Eq. 11 (Pa s); c, concentration (°Brix); D, coefficient in Eq. 11 (–); E, coefficient in Eq. 11 (–); k,k',k'', coefficients in Eq. 15 (ln Pa); K, consistency coefficient (Pa s^n); K_0, datum consistency coefficient (material specific) (Pa s^n); L, Judd-Hunter visual luminance (–); n, flow behavior index (–); n_0, datum flow behavior index (material specific) (–); p, pectin content of serum (wt%); PS, pulp:serum wet weight ratio; R, shear stress (Pa); R_Y, yield stress (Pa); T, absolute temperature (K); U_0, odor unit (–); x_p, mass fractions of protein (–); x_s, mass fractions of solids (–); x_f, mass fractions of fiber (–).

Greek Symbols

$\dot{\gamma}$, shear rate (s^{-1}); μ, dynamic viscosity (Pa s); μ_a, apparent viscosity (Pa s); μ_{100}, apparent viscosity at a shear rate of 100 s^{-1} (Pa s); μ_p, plastic viscosity (Pa s).

Abbreviations: ANICAV, Associazione Nazionale Industriale Conserve Alimentari Vegetali, Italy; BCR, Community Bureau of Reference, Brussels; CIPC, The Comite International Permanent de la Conserve; EC, Commission of the European Communities; FAO/WHO, UN Food and Agriculture Organization/World Health Organization; FDA, U.S. Food and Drug Administration; FMF, Food Manufacturer's Federation, U.K.; HTST, high temperature short time; MVR, mechanical vapor recompression; NTSS, natural tomato soluble solids; PG, polygalacturonase; PME, pectin methylesterase; TC, tomato color; TSS, tomato soluble solids; USDA, United States Department of Agriculture.

I. INTRODUCTION

A. The Volume of Tomato Production

In terms of dollar value, the tomato (*Lycopersicon esculentum*) is the world's second largest vegetable crop, with world production exceeding 70 million tonnes in 1993.[64] Tomatoes may be consumed fresh or, because of their perishable nature, processed to give canned whole peeled tomatoes. Tomatoes may also be processed to give tomato juice and concentrated tomato juice, tomato puree, and tomato paste. Tomato puree and paste may be marketed directly to the consumer or it may be an ingredient in other products, for example, tomato ketchup, soup, and sauces. The U.S. is not only the world's largest producer of tomatoes but is also the world's largest processor (see Table 1), accounting for about 50% of world production of tomatoes for processing in 1990.[64]

The U.K. imports tomato puree and tomato paste mainly from southern Europe, the eastern Mediterranean, and north Africa.[55] At one time most of the tomato paste imported for manufacture was 'double concentrate', which contains 28 to 30% total solids, but nowadays 'triple concentrate', which contains 38 to 40% total solids, is used more widely.[55]

B. Definitions

There is some confusion in the literature concerning the definitions of concentrated tomato juice, tomato pulp, tomato puree, and tomato paste. However, Goose and Binstead[22] and Gould[23] give the following useful definitions:

- **Tomato pulp** refers to the crushed tomatoes either before or after the removal of skins and seeds.
- **Tomato juice** refers to the juice from whole crushed tomatoes from which the skins and seeds have been removed and which has been subject to fine screening, and is intended for consumption without dilution or concentration.

TABLE 1
World Production of Processing Tomatoes in 1990 by Country[64]

Country	Production (million tonnes)
United States	9.307
Italy	3.850
Turkey	1.500
Greece	1.150
Spain	1.134
Portugal	0.760
Canada	0.580
France	0.540
Mexico	0.365
Israel	0.300
Taiwan	0.182

- **Tomato paste** is the product resulting from the concentration of tomato pulp, after the removal of skins and seeds, and contains 24% or more natural tomato soluble solids (NTSS). Tomato paste which is marketed to the consumer in small packs and sold as a condiment may also be described as tomato puree.
- **Tomato puree** is the term applied to lower concentrations of tomato paste (containing 8% to less than 24% NTSS). Rather unfortunately, tomato puree in the U.S. can also be called 'tomato pulp'. A further complication in the U.S. is that if the tomato puree satisfies certain legislative criteria it can also be called 'concentrated tomato juice'.
- **Tomato serum** is tomato juice which has been filtered or centrifuged to completely remove suspended solid material.
- **Pulp** refers to the suspended solid material in tomato juice, puree or paste which can be separated by centrifugation.
- **Tomato syrup** is tomato serum which has been concentrated.

C. The Problem of Defining Quality

The principal quality parameters for tomato paste are color, consistency and flavor and in addition there are compositional standards. A problem that has not been resolved and that has been the main cause of disputes among companies dealing with tomato products is the absence of a world-wide standardization of methods and instruments to define tomato paste quality and composition. While most of the major tomato-processing firms have quality control procedures, the techniques and methods applied are not always reliable. Moreover, methods of analysis may vary from country to country, and in some countries there are no official methods of analysis.[52]

II. GROWTH, RIPENING AND COMPOSITION OF TOMATOES

A. Growth and Ripening

It takes about 6 to 7 weeks for tomatoes to reach their full size from flowering followed by about 12 days to ripen. During ripening, the tomato changes from green to red as chlorophyll is destroyed and lycopene is synthesized. There is also increased production of the volatile compounds which generate aroma. During growth, the plant forms insoluble protopectin that firmly binds cell walls together.[23] Pectin is also associated with cellulose to form plant cell walls. During ripening, p rotopectin is converted to soluble pectin by the enzyme protopectinase, and the pectin so formed binds the cells together but less firmly. If the fruit is allowed to grow past maturity, the pectin itself is broken down into soluble compounds by the pectinolytic enzymes polygalacturonase (PG) and pectin methyl-esterase (PME), and the fruit becomes soft and mushy.[23] The enzyme endopoly-galacturonase (PG) is synthesized during ripening, but in the whole fruit the action of PG is limited by a number of factors. These include the amount of calcium bound to pectin, the distribution of PG in the cell walls, and the extent of methyl esterification of polygalacturonate.[41]

During the comminution of tomatoes to pulp for paste and puree manufacture, the enzymatic depolymerization of pectin by PG and PME can bring about a large reduction in the viscosity of the product[64] unless action is taken to heat denature the PG and PME enzymes by 'hot breaking'. The enzymes have a high optimum temperature of 60 to 66°C and only become inactivated at a temperature of about 82°C.[23] Thus, 'hot breaking' requires that the tomato pulp be heated as quickly as possible to 82°C or above to denature PG and PME, retain pectic substances, and preserve as much of the potential viscosity as possible. However, some loss of pectic substances is inevitable, even when the crushed tomato pulp is heated rapidly.[44]

B. Composition of Whole Tomato

The tomato fruit comprises skin, pericarp, and locular contents. The locular cavities are filled with jelly-like parenchyma cells that surround the seeds. The cell walls are composed of α-cellulose, pectins, hemicellulose, and some protein.[41] Tomato-based products consist mainly of disintegrated cells of the pericarp suspended in a clear serum. Of the 5 to 10% dry matter in the whole ripe fruit, about 75% is soluble.[28] Such a wide variation in the dry matter content is due to tomato variety, the nature of the soil in which the tomato is grown, and the amount of rainfall during the growing and harvesting season.[23] Nearly half the total dry matter consists of the reducing sugars glucose and fructose, about 10% is organic acids, principally citric and malic acids, about 1% is skin and seeds, with the remainder being alcohol-insoluble solids (cellulose, pectins, hemicelluloses, and proteins), minerals (mainly potassium), pigments, vitamins, and lipids.[50] The organic acid content is responsible for a pH between 4.2 and 4.6.[38] Glutamic acid is the principal amino acid found in tomato.[23]

III. TOMATO PUREE PRODUCTION

The basic sequence of operations in the production of canned tomato puree from raw tomatoes, based on an economic study of a typical, medium-sized Italian plant,[45] is shown in Figure 1.

A. Washing, Sorting, and Trimming

In modern plants, tomatoes are washed in water tanks agitated with compressed air, followed by rinsing with high-pressure water sprays to remove spray residues, microorganisms, dirt, mold, *Drosophila* (fruit fly) eggs, and larvae adhering to the fruit.[23] The wash water is chlorinated to 5 to 10 ppm to maintain sterility. Unfit whole fruit is picked out and discarded, while partly defective fruit is trimmed by hand. Sorters and trimmers remove off-color fruit or parts. They also trim rotten areas, mold portions, insect damage and sunscald.[23] This is the final control point for ensuring a low mold count in the final product (see Howard Mould Count).

B. Breaking

In the process described by Moresi and Liverotti,[45] the washed tomatoes are chopped into small pieces by a rotary comb chopper, and the chopped tomatoes are pumped into a heat exchanger and preheated to either 60°C for a 'cold break' or preheated to 90 to 95°C and held for 1 to 2 min for a 'hot break'. A 'hot break' juice has a high consistency due to better extraction of pectic substances, and due to retention of pectin by denaturation of the enzymes that would have caused its breakdown. A 'cold break' juice has a low consistency due to the activity of pectolytic enzymes and gives greater serum separation.[60] The advantages of cold breaking over hot breaking may be summarized as:

1. The juice is less likely to foul heat exchangers and evaporators[45]
2. The juice is easier to pump[22]
3. Higher final concentrations of tomato paste are possible[5]
4. The final paste has a more natural color and a fresher tomato flavor[64]

Morris[46] describes a plant in the U.S. that regularly produces both 'hot break' and 'cold break' tomato paste with 31% NTSS and 42% NTSS, respectively. The breaking process is varied to suit the intended use of the paste;[65] a 'hot break' process is selected

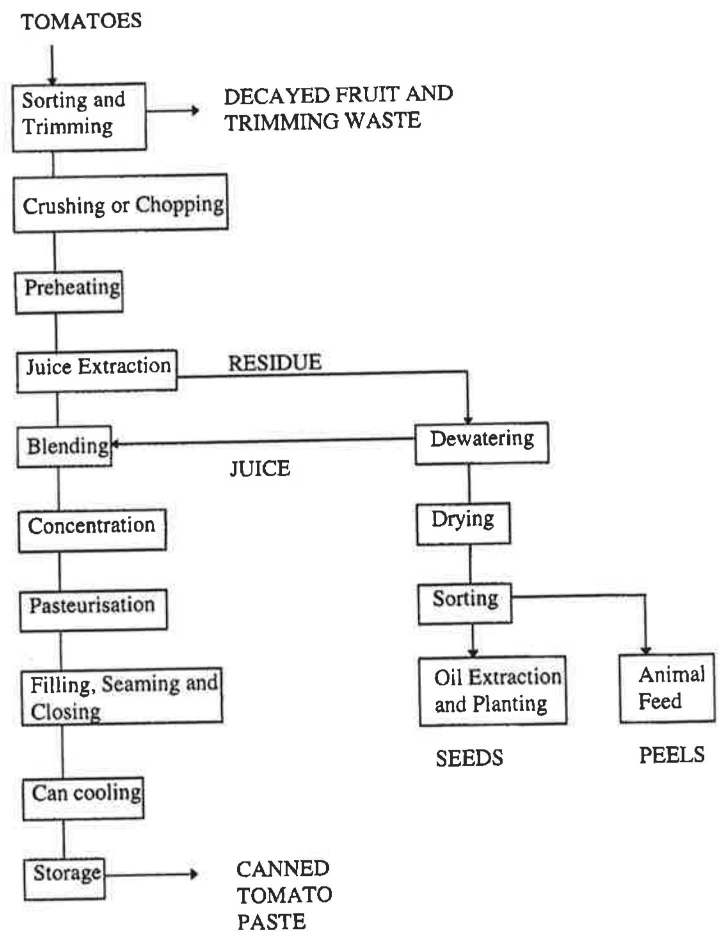

FIGURE 1. Flow diagram for canned tomato paste production, after Moresi and Livarotti.[45]

if the final paste is required to have a high viscosity for use in products such as pizza sauce and ketchup, and a 'cold break' process is suited to paste that is intended to be diluted for tomato juice and vegetable cocktails.[46] Vitamin C losses due to oxidation during crushing and breaking can be partly overcome by deaerating the tomatoes immediately after crushing,[23] or, better still, the tomatoes can be sliced and subject to breaking under vacuum to prevent oxidation.[46]

C. Juice Extraction

The heated tomato pulp is passed through two (or three) juice extractors to remove the skin and seeds, and to squeeze the juice out of the remaining pulp.[22] Juice extractors may be either of the screw type or paddle type; a screw-type extractor uses an expanding helical screw to subject the pulp to increasing pressure against a screen, whereas a paddle-type extractor beats the pulp against a screen.[22] Moresi and Liverotti[45] describe two juice extractors of screen size 1.5 and 0.4 mm, respectively. In the terminology of the tomato processor the first juice extractor is known as a 'pulper' and the second juice extractor is known as a 'finisher'.[46] Moresi and Liverotti[45] reported the yield of tomato juice from the juice extraction stage to be 95.0%. A further screw press may be added to extract more juice from the residue leaving the juice extractors. Blending of the juice from this dewatering stage with that leaving the juice extraction stage raised the overall yield to 96.3%. In addition, seeds in the residue may be recovered from the residue for planting or oil extraction, and the peel may be recovered for animal feed or fuel, although such treatment of the residue may be uneconomic.[45]

Gould[23] suggests that considerably lower extraction rates may be appropriate in tomato juice manufacture. The percentage of juice extracted for concentration affects flavor and, where the end-product is intended for sale as tomato juice, the pulper and finisher are set to give an approximate 70% yield. At this extraction rate, the juice will have relatively more soluble solids, which improve flavor, and a lower proportion of insoluble solids, which may adversely affect quality.[23,64] Juice yield is increased by increasing either the pulper/finisher blade speed or the screen size.

In general, the finisher screen size is selected to control the 'texture' of the final tomato paste so that, for example, for a pizza sauce a coarse texture paste is required, while a finer screen size is used to produce paste intended for dilution to tomato juice.[46] Both the diameter of the apertures in the finisher screen and the finisher blade speed determine the particle size distribution of suspended particles, and this in turn significantly affects the viscosity of tomato juices and concentrates.[61] However, contradictory evidence regarding the effect of the size of suspended particles on viscosity has been reported,[31,56,61] and Tanglertpaibul and Rao[61] suggest that competing mechanisms result in the selection of an intermediate screen size for maximum apparent viscosity. These workers found that a finisher screen size of 0.686 mm gave a higher apparent viscosity (at a fixed shear rate), for both tomato juices and concentrates, than either smaller (0.508 mm) or larger (0.838 and 1.143 mm) screens. In a similar experiment,[48] at a fixed blade speed, a screen size of 1.0 mm was reported to give juices and purees of higher consistency (i.e., increased viscosity) than did smaller (0.5 mm) and larger (1.5 mm) screens.

D. Concentration

Tomato juice is concentrated by evaporation under partial vacuum either in a batch or continuous process. In the traditional batch process, the evaporation may be entirely carried out in steam-jacketed vacuum pans (known as 'boules') fitted with agitators, or the juice may be preconcentrated in a tubular evaporator to about 12% solids before transfer to the boules.[22] Evaporation at low pressure reduces the boiling point of the juice so that the resulting paste retains most of its color and flavor.[23]

Continuous processes tend to produce a more consistent paste than batch processes.[22] Multiple-effect evaporators with backward feed are used to obtain improved steam economy because energy consumption for evaporation is the second highest production cost after raw materials.[37] The concentration of tomato juice for paste results in a large increase in viscosity. Consequently, early continuous double effect evaporators, such as the Manzini 'Titano' and the large Rossi and Catelli 'D. F. F.' series, used a rotary steam coil or forced circulation in the first effect (which experiences the highest temperature and deals with the most concentrated juice) to ensure adequate circulation of the concentrate.[22] Such circulation prevents burn-on fouling and improves heat transfer.

More recent evaporators use up to four effects with forced circulation such as the quadruple effect Rossi and Catelli 'Venus' system,[2] or double or triple effects with scraped surface evaporation.[5] An alternative method for improving energy efficiency is the use of a single forced circulation evaporator with mechanical vapor recompression (MVR), in which all the vapor produced in the evaporator is compressed and returned to the steam side of the calandria, at an increased enthalpy, to heat the feed.[2,8] A single-stage MVR system is generally more energy efficient than a triple-effect evaporator.

E. Pasteurization

Continuous pasteurization of tomato paste at 90 to 92°C, before it is canned, prevents subsequent spoilage by lactobacilli.[45] A gear pump transfers viscous tomato paste from the evaporator to a filler. The filler usually comprises a receiving tank for the tomato paste, a tubular heat exchanger for pasteurization, and a recirculation tube. The recirculation tube returns the hot paste to the receiving tank if flow through the filling nozzles is restricted, to prevent 'burn-on' fouling of the heat exchanger and loss of product quality.[22]

F. Filling, Closing, and Cooling

The pasteurized paste is automatically hot-filled into lacquered tin cans that have been presterilized with steam.[45] The cans are immediately seamed, inverted to sterilize the lids, and held for about 3 min prior to cooling.[22] Canned tomato paste may be described as a conduction pack and unless the cans are cooled as quickly as possible the retention of heat leads to deterioration of flavor and color. Cans may be air cooled or water cooled. Air cooling simply requires that the cans be stacked in rows with air spaces in between to allow the passage of an air current.[22] Water cooling involves agitating the cans for about 2 h under a spray of atomized water that has been chlorinated to 15 ppm residual chlorine.[23]

IV. MICROBIOLOGICAL ASPECTS

The microorganisms of concern in tomato puree and paste are lactobacilli, *Bacillus coagulans*, and *Clostridium pasteurianum*, which can cause spoilage, and *Clostridium botulinum*, which is a pathogen. Pasteurization destroys nonsporing spoilage microorganisms such as lactobacilli, but has little effect on the heat-resistant spores of *Bacillus coagulans*, which are known to cause flat-sour spoilage of tomato juice, especially when the pH is 4.35 or higher.[23] Spoilage of tomato juice may also be caused by the heat-resistant spores of *Clostridium pasteurianum*, which is a gas-forming butyric anaerobe.[7,23] The effectiveness of pasteurization in preventing spoilage of tomato concentrates has been attributed to lowered water activity as a result of the concentration process and the presence of hydroxymethyl furfural.[23]

Nonsporing bacteria and yeasts should be absent from canned tomato puree and paste unless there has been underprocessing, defective can seaming, post-process seam leakage, or can damage.[55] The pH of canned tomato paste or puree normally falls within the range 4.0 to 4.4,[55] which places it in the acid category[30] for canned foods (pH 3.7 to 4.0 to 4.6). While this pH is below the critical value of 4.5 for the outgrowth of the endospores of *Clostridium botulinum* and other pathogens,[8] there has been a tendency in recent years with Italian tomatoes toward higher pH values,[55] which may place the puree and paste made from such tomatoes at risk. Because a pH below 4.5 is the only assurance that the puree is safe, it is unusual not to find specifications for pH, for example, in FMF Trade Specification.

The standard pack for pasteurized industrial tomato paste was once the '5-kilo' can,[22] but nowadays tomato paste for industrial use is subject to high-temperature short time (HTST) treatment, cooled and packaged aseptically, rather than pasteurized and canned.[46,55] The heat treatment of tomato paste for aseptic packaging is carried out in a heat exchanger and holding tube and a typical HTST treatment is 108.9°C for 2.25 min. The paste is then cooled to 37.8°C before being pumped to a feed tank and aseptic filling, typically into steam-sterilized bag-in-drum or bag-in-crate systems of 55 or 300 gallon capacity.[46]

V. STANDARDS AND SPECIFICATIONS

A. Gradings of Tomato Paste and Puree

With respect to composition and quality,[22,23,36,55] the following official bodies have proposed standards:

1. The FAO/WHO Codex Alimentarius Commission, Committee on Processed Fruit and Vegetables
2. The United States Department of Agriculture (USDA) and other state departments
3. ANICAV (Italy)
4. The Fruit and Vegetable Sub-Committee of the Food Legislation Working Party of the Commission of the European Communities (EC)
5. The Comite International Permanent de la Conserve (CIPC)

In the U.K., the Food Manufacturer's Federation (FMF) produced a Trade Specification for Tomato Puree that was adopted as a minimum industry specification in 1967 and based on the CIPC Standard of 1958 with some modifications to take into account a number of user requirements.[59]

Tomato pastes and purees contain both soluble and insoluble solids with about 87.5% of the total dry solids being soluble and 12.5% being insoluble in hot distilled water.[22] The total dry solids content of a sample is determined by drying in a vacuum oven at 70°C[36] or by drying in a microwave oven (AOAC Official Method 985.26)[4] and is reported as '% total solids'. This is sometimes expressed as % dry solids. The soluble solids content is determined by refractometer (AOAC Official Method 970.59),[4] and the soluble solids content is reported as 'Natural Tomato Soluble Solids (NTSS) as % sucrose'. It is recognised that salt added in the course of processing affects the refractometer reading, and for grading purposes it is necessary to make an appropriate correction so that the soluble solids content is determined exclusive of added salt.[23] This correction is included in the AOAC Official Method. In the research literature the soluble solids content is often expressed as % NTSS or simply as °Brix.

Gradings of tomato paste and puree have been proposed using either % total solids or NTSS as a basis. The five basic gradings of tomato paste under Draft EC proposals are based on minimum % dry solids content with a tolerance of 5% as follows:[22]

- Semi-concentrated tomato puree (paste) 12%
- Single concentrated tomato puree (paste) 18%
- Double concentrated tomato paste 28%
- Triple concentrated tomato paste 36%
- Sextuple concentrated tomato paste 55%

The tolerance of 5% allows the processor to manufacture products with 95% of the dry solid values listed above. For example, a double concentrate may contain 26.6% dry solids as an absolute minimum. With commercial purees and pastes it is usually the case that single concentrate contains 18 to 20% dry solids, double concentrate 28 to 30% dry solids, and triple concentrate 38 to 40% dry solids.[55]

The Codex Standard for Processed Tomato Concentrates is different, with seven gradings defined in relation to minimum tomato content. The Codex Standard also defines tomato puree as containing not less than 8% but not more than 24% NTSS and tomato paste as containing at least 24% NTSS.[36] The USDA Standards (1978) define four gradings of tomato puree, and the USDA Standards (1977) four gradings of tomato paste, based on the percentage of NTSS. It is important to note that NTSS, rather than % dry solids, is the basis for grading in the U.S. These gradings are as follows:

- Tomato puree
  - Light concentration — 8.0% ≤ NTSS 10.2%
  - Medium concentration — 10.2% ≤ NTSS 11.3%
  - Heavy concentration — 11.3% ≤ NTSS 15.0%
  - Extra heavy concentration — 15.0% ≤ NTSS 24.0%
- Tomato paste
  - Light concentration — 24.0% ≤ NTSS 28.0%
  - Medium concentration — 28.0% ≤ NTSS 32.0%
  - Heavy concentration — 32.0% ≤ NTSS 39.3%
  - Extra heavy concentration — 39.3% NTSS or more

B. Additives to Tomato Paste and Puree

Under Draft EC proposals, it is permitted to add salt to a maximum of 10% of the dry solids. It is also permitted to add certain aromatic herbs, spices, or spice extracts, and these must be indicated on any label.[36] No other ingredients or additives are permitted, particularly sugars, colors, or thickeners. The Codex Standard for processed tomato concentrates allows the addition of various acids and sodium bicarbonate.[36] In the U.S., the Food and Drug Administration (FDA) permits the use of hydrochloric acid and sodium hydroxide as processing aids in both tomato puree and paste manufacture. However, salt is the only seasoning allowed in tomato puree, while salt, spices, and flavoring are permitted in tomato paste, as well as sodium bicarbonate to neutralize a part of the tomato acids.[23]

C. Compositional Standards for Tomato Paste and Puree

Tomato paste or puree may be analyzed for any of the following:

1. Total solids
2. Soluble solids
3. Insoluble solids
4. pH
5. Total acidity as citric acid
6. Volatile acidity as acetic acid
7. Salt content
8. Ash content
9. Total sugar content as invert sugar
10. Copper content
11. Arsenic, lead and tin content
12. Ascorbic acid (vitamin C)
13. Tomato content
14. Preservatives (sulfur dioxide, benzoic acid, and hydroxybenzoates)
15. Color
16. Flavor and odor
17. Hydroxymethyl furfural
18. Consistency
19. Serum separation
20. Black specks, brown specks, and traces of pigment (red specks)
21. Pieces of skin, seeds, cores, and leaves
22. Mould (Howard mold count)
23. Fly-egg count
24. Insect fragment count

Under Draft EC proposals, tomato paste, and puree is defined as either being of 'standard' quality or 'extra' quality (see Table 2).

TABLE 2
Quality Standards for Tomato Paste and Puree Based on Draft EC Proposals Expressed as a Percentage of Dry Solids[22,36]

	Standard quality	Extra quality	Not for sale
Total sugars (as invert sugar) (min.)	45	50	Less than 35
Titratable acidity (as citric acid monohydrate) (max.)	10	9	Above 12
Volatile acidity (as acetic acid) (max.)	0.30	0.15	
Mineral impurities insoluble in water (max.)	0.10	0.05	Above 0.15

In addition, tomato puree may not be sold or reworked if it possesses even one of the characteristics indicated in the table as 'not for sale'.

Limits have been recommended for the levels of trace metals (copper, lead, arsenic and tin) based on the dry solids content (not including added salt). In the U.K., the 'Report on Copper' made by the Food Standards Committee (1956) recommended a maximum limit for copper of 100 ppm.[22] The FMF Trade Specification for Tomato Puree (1967) recommended a lower maximum value for copper of 50 ppm and a maximum arsenic content of 1 ppm. The FMF also recommended maximum lead contents of 3 ppm for purees of 15 to 20% solids and 5 ppm for purees of 25% solids or more.[55] The Codex Standard set a limit of 250 ppm for tin.[36] Copper contamination from equipment was a serious problem, but nowadays the replacement of copper and brass with stainless steel has meant it is unusual to find puree containing more than 5 ppm copper.[55]

VI. COLOR AND APPEARANCE

A. Factors Affecting Color

The puree should be of a good, bright red color and free from black specks, insects, or other foreign matter.[55] Color in the tomato is due to the presence of carotenoids; lycopene is the major carotenoid, comprising about 83% of the total pigment present with beta-carotene accounting for about 3 to 7% of the total.[24] The quantity of carotenoids depends on the tomato variety and the growing conditions. A lower carotene content is found in greenhouse-grown tomatoes in summer or winter than tomatoes produced outdoors during summer and also in fruits that are picked green and ripened in storage compared with fruits ripened on the vine.[24] The carotenoids in tomatoes are subject to degradation during processing. The main cause being oxidation,[23,64] which depends on:

1. Availability of oxygen
2. Low water activity
3. High temperature
4. The destabilizing presence of prooxidant metal ions such as copper and iron
5. The stabilizing presence of antioxidants and lipids

Oxidation is enhanced by the use of fine screens in juice extraction due to the large surface area exposed to air and metal.[32] The formation of brown pigments due to Maillard reactions (and caramelization of sugars) may occur in processed tomato products and depends on the amount of sugar and amino acids present, as well as the pH and the time and temperature of processing.[64] Black or brown specks may be caused by burn-on in heat exchangers, excessive black rot on tomatoes due to poor sorting or trimming, the presence of foreign matter, or a damaged screen or faulty cyclone.[22] In 'extra' quality tomato puree no more than 10 black or brown points are permitted in a 10-g sample and not more than 5 are permitted with diameters over 0.5 mm.[22] Some manufacturers have their own specifications. The Heinz Company specification for cold break tomato paste[27] requires that an 8- to 10-g sample of paste is placed between two transparent glass plates, and the plates rotated to give a thin film that is then read against a red metallic plate. Black specks are classified as small (0.5 to 1 mm), medium (1 to 1.5 mm), or large (>1.5 mm). A maximum of 7 specks is allowed, with only 2 of medium size. The presence of any large specks indicates severe thermal abuse of the product during processing.

According to Brimelow,[9] the following improvements in processing technology have greatly improved processed tomato product color:

1. The replacement of batch concentrators (boules) with continuous concentrators
2. The use of triple or quadruple effect evaporators for more efficient evaporation
3. The use of short residence time breaking equipment at very high break temperature
4. The use of more efficient cooling equipment combined with aseptic filling of containers

B. Measurement of Color

A number of different methods have been used to determine the color of tomato products:

1. The Munsell Spinning Disk Colorimeter
2. Tristimulus color meters
3. Reflectance spectrophotometers
4. The Lovibond Tintometer

The Munsell Spinning Disk Colorimeter and the Lovibond Tintometer are subjective methods of color measurement using the human eye, while Tristimulus color meters and reflectance spectrophotometers are objective. A number of limitations have been suggested[22,23] when the human eye judges color:

1. The eye is unable to distinguish small color differences in a nonhomogeneous surface
2. A suitable color standard is needed for comparison
3. Eye fatigue can occur relatively quickly

However, it was not until 1977 that photoelectric colorimeters became reliable enough to be accepted as a commercial means of color-grading tomato products,[29] although there is currently[9] no standard method used across Europe for the measurement of the color of tomato paste.

C. The Munsell Spinning Disc Colorimeter

From 1938 to 1977 the sole USDA Standard method of color assessment was based on colored papers made by the Munsell Company.[29] The principle of the Munsell Spinning Disc System is that a number of different-colored discs with radial slits can be interleaved on a spindle and rotated at high speed to give the impression of a single color. A sample diluted to 8 to 9% NTSS is placed next to the disc under identical and carefully specified conditions of illumination. The disc is spun and stopped and the interleaving of the colored discs adjusted until a visual color match is obtained. The color of the sample is defined in terms of the identity of the individual discs and the percentage area of each disk exposed by the interleaving. The Munsell

TABLE 3
USDA (1977, 1978) Color Grade Standards for Tomato Paste and Puree[23]

	Disc 1. Red (5R 2.6/13) Glossy finish	Disc 2. Orange (2.5YR 5/12) Glossy finish	Discs 3 and 4. Any combination of Black (N1) Glossy finish with Grey (N4) Matt finish
USDA Grade 'A'	65%	21%	14%
USDA Grade 'C'	53%	28%	19%

system of color classification is based on the properties of hue, lightness, and color saturation (chroma). Each disc is coded in terms of 10 hues that are further subdivided into 10 shades. Levels of lightness range from 0 at black to 10 at white. There are 18 levels of chroma ranging from 0, which is a neutral gray to 18, which represents maximum color saturation. Table 3 lists the discs and percentages of disc area specified by USDA Standards for tomato paste (USDA, 1977) and puree (USDA, 1978).

Samples must match or contain more 'red' than the color percentages specified by the USDA Standards. Any combination of neutral black or gray is acceptable. According to Gould,[22] a greater percentage of gray over black may be necessary to match the sample for cold-break extracted and HTST-sterilized tomato juice, and a greater percentage of black over gray required to match hot-break extracted and conventionally processed tomato juice. The USDA Standards also include a quality scoring system such that Grade A may be scored 45 to 50 points, Grade C may be scored 40 to 44 points, and substandard samples may be scored 0 to 39 points.

D. Tristimulus Color Meters

Although the Munsell Spinning Disc System is still in wide use, the USDA published amendments to the 1977 and 1978 standards for grades of tomato pastes and other tomato products that allowed for objective measurements of color. These amendments arose from collaborative work carried out by the University of California, the USDA, the California Canners' League, and manufacturers of Hunter, Gardner, and Agtron instruments.[9] The Hunter and Gardner instruments are tristimulus color meters that attempt to imitate the response of the human eye to color, while the Agtron is an instrument that measures reflectance at 640 nm and 546 nm. The principle of the tristimulus color meter is that a standard light source is shone at an angle of 45 onto the sample and the light reflected perpendicular to the sample is split into three beams. Each beam passed through a red, green, or blue glass filter and measured by a specific photocell. Before use the color meter is calibrated against standard black and white tiles and also against a standard tile similar in color to the sample to be measured. The latter tile is known as a 'hitching post' standard.[23] The Hunter and the Gardner instruments generate the following values:

- L, the visual lightness or luminance of the sample on a scale of 0 to 100 (0 = perfect black, 100 = perfect white, 50 = a medium gray).
- a, the redness/greenness of the sample. The scale gives positive values for red,

negative values for green, and zero for gray.

- b, the yellowness/blueness of the sample. The scale gives positive values for yellow, negative values for blue, and zero for gray.

The values L, a, and b are known as the Judd-Hunter values and these may be represented as a point in three-dimensional space within the Judd-Hunter color solid.[21] In the U.S., L, a, and b values are related to USDA scores by equations specific to the particular tomato products.[29] Alternatively, many suppliers and buyers of tomato products simply use these values or derivations of them, such as the a/b ratio or the tomato color (TC) index. The TC index[71] is defined by

$$TC = \left(\frac{a}{L}\right)\left(a^2 + b^2\right)^{-1/2} \qquad (1)$$

While the a/b ratio indicates the relationship between redness and yellowness in the sample, the TC index gives a more precise description of color for grading purposes, because it takes account of the luminance factor.[22]

According to Goose and Binstead,[22] an a/b ratio of 1.90 or greater represents a first quality product in terms of color and an a/b ratio of less than 1.80 means that the paste or puree may be unacceptable for inclusion in products where a bright red color is desired. These values may now be seen as out-of-date owing to significant improvements in the color of tomato paste brought about by improved processing technology. Petrotos[51] pointed out that most existing specifications for tomato concentrate diluted to $12.5 \pm 0.1\%$ NTSS demand a minimum L value of 23.5 and minimum a/b value of 2.15 as borderlines for an acceptable color.

Work toward establishing a European standard method for the measurement of tomato paste color[9] has been based on the use of a tristimulus colorimeter and a defined reference tile as a 'hitching post'. In early work, the tile was a red-colored card from the Swedish National Standard Color Atlas[1] chosen for its close similarity to tomato paste,[34] with the following Judd-Hunter values: $L = 25.16$, $a = 26.00$, $b = 13.14$. However, Brimelow[9] recommended that the standard European reference tile for the color measurement of tomato paste should have the following approximate color values: $L = 25$, $a = 32$, $b = 14$ ($a/b = 2.3$). Follow-up work by Kent and Porretta[35] used the BCR reference tile (Community Bureau of Reference, Brussels) with Judd-Hunter values of $L = 25.8$, $a = 33.9$, $b = 14.8$, $a/b = 2.29$.

Brimelow[9] further pointed out that Judd-Hunter values are affected by dilution, particularly below 8 to 10% NTSS, and suggested that color measurement should be carried out on tomato paste diluted with deaerated distilled water to 12% TSS (tomato soluble solids) at 20°C, rather than at the USDA Standard dilution of 8.5% TSS, because errors in dilution at the higher concentration have less effect on measured a and b values.

E. The Lovibond Tintometer

The Lovibond Tintometer may be used for routine quality control purposes[55] because of its simplicity. The principle used in this instrument is that half the field of view in a viewing tube is occupied by the illuminated sample, while the other half is occupied by light reflected from a white surface that has passed through colored glasses mounted on racks. The glasses are made in numbered graduations of the subtractive primary colors, (red, yellow, and blue). A good tomato puree color would match with 20 or more Lovibond red units, 7 or fewer yellow units, and 2 or fewer blue units. According to Kirk and Sawyer,[36] red should predominate over yellow, and an excess of blue may indicate scorching of the puree.

VII. CONSISTENCY AND SERUM SEPARATION

A. Measurement of Consistency

Consistency is important in the preparation of ketchup and sauces where a thick product is required and in which tomato puree is the main thickening agent.[59] In addition, high-consistency puree reduces the cost of such products to the manufacturer because the same gross viscosity is obtained with a lower tomato solids content.[64] There are no guidelines for the measurement of consistency of tomato paste and puree in the USDA Quality Grade Standards,[23] although standards have been established for the measurement of the consistency of catsup and tomato sauce using a Bostwick Consistometer. This empirical method involves placing the sample, without incorporating air bubbles, into the metal trough of the instrument to a set level at 20°C. One wall of the trough is a metal gate that can be opened almost instantaneously, allowing the sample to flow under its own weight into a longer trough that is calibrated in 0.5-cm steps. The distance traveled by the sample in centimetres in 30 s is the Bostwick Consistency. Grade A tomato sauce flows not more than 14 cm (9 cm for catsup) in 30 s at 20°C and Grade C tomato sauce flows not more than 18 cm (14 cm for catsup) under the same conditions.

Despite the absence of official Standards, the Bostwick Consistometer has been used widely in the tomato industry. However, a limitation of the Bostwick Consistency is that its magnitude decreases exponentially with concentration, so that data cannot be obtained on viscous concentrates with more than about 15% total solids.[43] Therefore, it is necessary to dilute the sample to 12% NTSS[9] or 12.5 ± 0.1% NTSS[27] to obtain a reasonable reading. The Heinz Company specification, at 12.5 ± 0.1% NTSS, for the Bostwick consistency is that cold break tomato concentrates should travel 7 to 14 cm in 10 s and hot-break tomato concentrates should travel 7 to 10 cm in the same period.

In addition to the simple measurements already described, the consistency of tomato puree and paste, for quality control and trade purposes, has been measured empirically with various other penetrometers, consistometers, and viscometers. These instruments have been reviewed by Gould,[23] who reported apparent viscosities of 20 commercial tomato pastes from different manufacturers (at unspecified shear rate, concentration, and temperature) in the range 1.65 to 5.1 Pa s with 10 of the samples falling in the range 3 to 4 Pa s.

B. Factors Affecting Consistency

The main factors[39,40,55,70] governing the consistency of tomato paste and puree are

1. Compositional differences between cultivars
2. Compositional variation of a cultivar at different stages of maturity
3. The total solids content and insoluble solids content
4. The particle size distribution and particle shape of the insoluble material
5. The break temperature

Increasing the total solids content by evaporation leads to a rapid rise in apparent viscosity. While both serum and pulp contribute to the apparent viscosity of tomato concentrates, the contribution of the dispersed solids (pulp) is much greater than that of the serum.[56]

The nature of the pulp (particle size distribution, linearity of the suspended particles, cell rupture, and fragmentation) considerably influences consistency and serum separation. The effect of pulper/finisher blade speed and screen size on particle size distribution has already been discussed. In the production of other tomato products, such as catsup and sauces (in which tomato puree or paste may be an ingredient), the product is milled before filling by a variety of machines in order to increase consistency.[23] Milling has the effect of changing spheroidal particles into elongated particles that offer a greater resistance to flow.[23] Typical equipment includes a Waring blender and piston-type and creamery homogenizers. Homogenization of tomato juice both increases the linearity of cell walls and causes a marked increase in the volume of particles due to rupture of the cellular envelope.[68] Increasing the pressure of homogenization of tomato juice from 0 to 3000 psi both increased viscosity and reduced serum separation[63] although increasing the homogenization pressure still further to 6000 psi had little additional effect. Similar findings had been obtained[26] with a piston-type homogenizer. The increase in viscosity was attributed to an increase in the linearity of cell walls and an increase in cell wall rupturing. Homogenization also leads to less serum separation because cells are ruptured and they are unable to settle as compactly as intact cells. In addition, mechanical disintegration releases microfibrils from the torn edges of the wall fragments and prevents efficient packing into a low-volume precipitate.[60]

Variations on the basic 'hot break' and 'cold break' methods have been used to influence pectin retention and consistency, for example, the 'thermal break' in which the tomatoes are chopped cold and held for a set period of time before rapid heating to 90°C, to control the viscosity of the end-product,[5] and the short residence-time 'super hot break'.[9] Besides preserving pectin by enzyme inactivation, a very high break temperature (107°C for 45 s) appears to increase consistency by two further mechanisms: first, more soluble pectin is leached from cell walls and second, cell structure is more highly disrupted.[70] On the other hand, prolonged heating at high temperature can lead to pectin denaturation and a reduction in consistency.[64]

C. Serum Separation

Tomato juice consists of suspended particles in a colloidal serum with most of the particles above about 150 μm in size.[62] The suspended particles (pulp) are made up of solids originating from the cell walls and other parts of the tomato and can be separated by centrifugation. The clear serum contains low- and high-molecular-weight solutes of pectic substances, sugars, salts, and organic acids.

Serum separation can be a quality problem because the homogeneous distribution of insoluble particles in the serum is lost. Although the suspended particles may tend to settle by sedimentation, it is the tendency of the particles to collapse under gravity and pack into a small volume that is the main cause of the problem.[57] Serum separation in tomato juice can be reduced by 'hot-breaking' or by homogenization. In commercial tomato juice production, cold-break tomato juice is generally homogenized before canning to increase consistency and reduce serum separation, while homogenization of hot-break tomato juice is often considered unnecessary.[22] Ultrasonic homogenizers, which are capable of dispersing solids, may be used with tomato juice[8] or the juice may be pressure homogenized at 1000 to 1500 psi and 66°C.

A simple measure of serum separation is a blotter test where a small sample of the puree or paste (about 1 g) is applied to the center of a filter paper marked with concentric circles. The distance moved by the serum after a certain time (5 or 10 min) is an indication of serum separation.[22] A more reliable test involves measuring the rate of drainage of serum from a sample held by a 42-mesh (355-μm aperture) stainless steel cone of 60° and 10 cm side length.[14]

D. Rheology of Tomato Paste and Puree

For a Newtonian fluid (Figure 2) there is a linear relationship between shear stress R and shear rate $\dot{\gamma}$ and the gradient of the line is equal to the dynamic viscosity μ. The equation of motion for a Newtonian fluid can then be written as

$$R = \mu\dot{\gamma} \qquad (2)$$

However, the majority of food liquids are non-Newtonian and at a particular value of $\dot{\gamma}$ it is necessary to define an apparent viscosity μ_a by

$$\mu_a = \frac{R}{\dot{\gamma}} \qquad (3)$$

The power law (Figure 2) is one of the most widely applicable of all rheological models and may be expressed as

$$R = K\dot{\gamma}^n \qquad (4)$$

where K is the consistency coefficient and n is a flow behavior index. For values of n less than unity the apparent viscosity decreases with increasing shear rate and such fluids are said to display *shear thinning*. (This is often, but not always accurately, referred to as pseudoplasticity). When n is greater than unity the fluid is said to be shear-thickening or dilatant. The consistency coefficient has SI units of Pa s^n and should not be confused with the apparent viscosity. A power law fluid cannot be said to have a viscosity as such; the apparent viscosity when flowing under shear depends on the rate at which that shear is applied and therefore, combining Eqs. 1 and 2,

$$\mu_a = K\dot{\gamma}^{n-1} \qquad (5)$$

The pulp content of tomato juice before concentration is about 25% by volume (which may vary with processing history), and it is the pulp that gives tomato juice its distinct rheological properties. If the pulp is centrifuged out the remaining serum shows almost Newtonian behavior.[13,49]

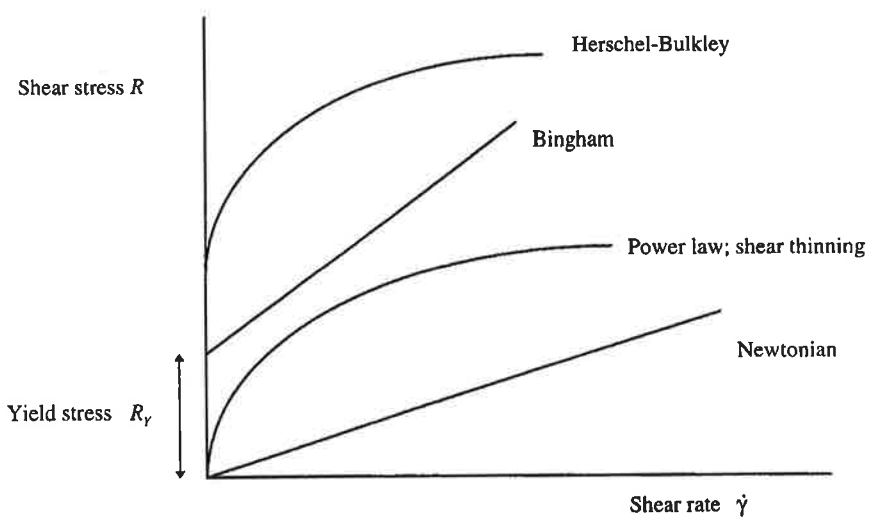

FIGURE 2. Flow curves for Newtonian, Bingham, power law, and Herschel-Bulkley fluids.

Tanglertpaibul and Rao[62] centrifuged tomato juice to remove the pulp and concentrated the serum separately to varying concentrations in the range 5.6 to 20°Brix. It was found that the serum fraction alone showed very slight shear thinning behavior, due to the presence of pectic substances, giving flow behavior indices in the range 0.91 to 1. The levels of pectic substances in the serum fraction ranged from 0.16% in the 5.6°Brix sample to 0.80% in the 20°Brix sample with corresponding viscosities at 25°C of about 6 and 16 mPa s, respectively. These serum viscosities were considerably less than the apparent viscosities measured after adding pulp back to the serum, which were well within the range 0.1 to 1 Pa s, indicating that viscosity was largely controlled by the pulp content.

A number of studies have found that the power law gives a good fit to shear stress-shear rate data for both tomato juices and concentrates,[19,56] and this assumption has been reported as satisfactory for engineering design purposes.[66] Values of the flow behavior index range from 0.22 to 0.26 for tomato concentrates,[56] 0.32 to 0.38 for commercial tomato ketchup,[54] and 0.351 to 0.426 for ketchup made by a hot break process,[6] all of which indicate a considerable degree of shear thinning.

Fito et al.[20] confirmed the shear thinning nature of concentrates and measured K and n as a function of temperature for concentrates produced by both hot- and cold-break methods. The variation of n with temperature was not found to be significant. The consistency coefficient was correlated with concentration as follows:

$$K = K_0 C^a \tag{6}$$

where a is dimensionless index and K_0 fitted an equation of the Arrhenius form. In contrast, Trifiro et al.[66] found both the consistency index and the flow behavior index to vary with temperature and suggested the following relationships

$$K = K_0 a^{1000/T} \tag{7}$$

$$n = n_0 + \frac{1000b}{T} \tag{8}$$

where K_0, a, n_0, and b are material specific constants and T is the absolute temperature. The power law and temperature-dependent values of K and n were then used to estimate the pressure drop in continuous 'tube-in-tube' heat exchangers used for the heat sterilization of tomato paste. However, there are no comprehensive studies reported in which the temperature and/or concentration dependence of these important parameters have been measured for a wide range of concentrated tomato products.

Tanglertpaibul and Rao[61] proposed the apparent viscosity at a shear rate of 100 s^{-1} (μ_{100}) as a suitable rheological characteristic for tomato concentrates. The effect of temperature on μ_{100} was well described by an Arrhenius relationship with values of the activation energy ranging from 2.0 to 3.0 kcal mol^{-1}. Increasing the total solids content of tomato concentrates increases viscosity considerably. The apparent viscosity was found[56] to depend on the total solids concentration of tomato concentrates raised to a power in the range of 2.0 to 2.5. A more detailed study[62] involved separating serum from hot-break tomato juice by centrifugation and adding varying levels of pulp (in the range –30 to +30% of normal values) to the serum at four levels of (serum) concentration to determine if a simple relationship existed between apparent viscosity at 25°C and pulp content that was independent of serum concentration. Expressing the pulp content of the tomato concentrate as a pulp:serum wet weight ratio (PS), the following relationship resulted:

$$\mu_{100} = -0.1934 + 1.3923PS \tag{9}$$

An unsatisfactory feature of this equation was that it implied a negative value of serum viscosity in the absence of pulp. Therefore, two further empirical equations were developed that satisfy the requirement that in the absence of pulp the apparent viscosity obtained is that of the serum. Hence:

$$\mu_{100} = \mu_{serum} + A(PS)^B \qquad (10)$$

and

$$\mu_{serum} = C + Dp^E \qquad (11)$$

The coefficient A indicates the contribution to viscosity of a unit amount of pulp and the coefficient B reflects the influence of pulp content on viscosity of concentrates from different tomato cultivars and/or processes. The magnitudes of the coefficients A and B are $A = 1.32$, $B = 1.485$ and for coefficients C to E (where p is the pectin content expressed as pectic substances wt% of serum): $C = 0.00492$, $D = 0.0153$, $E = 1.483$.

Dale et al.,[16] concerned with the specification of viscosity for use in reverse osmosis system design, developed an empirical equation for the apparent viscosity of tomato concentrates (at an unspecified shear rate) based on proximate composition and absolute temperature:

$$\mu_a = \left[1.44\times10^{-6}\exp\left(\frac{1928}{T}\right)\right]\left[1+18x_p\right] \times\left[1+0.295x_s\right]\left[1+333x_f\right] \qquad (12)$$

where x_p, x_s, and x_f are the mass fractions of protein, solids, and fiber, respectively. Although it is not made clear how the analysis was determined, Eq. 12 clearly shows the relative importance of fiber content to apparent viscosity.

Despite the attention given to the power law, there is evidence[56] that tomato juice and concentrates are not true power law fluids because they appear to possess a yield stress. A yield stress is characteristic of a Bingham fluid (Figure 2): at shear stresses below R_Y the fluid will not flow; however, when stresses greater than R_Y are applied the fluid behaves as a Newtonian liquid and the flow curve is linear. This behavior can be represented by

$$R = R_Y + \mu_p\dot{\gamma} \qquad (13)$$

where μ_p is known as the plastic viscosity. The most commonly used technique to obtain a value for yield stress is to extrapolate shear stress/shear rate data to zero shear rate according to the Herschel-Bulkley, Casson, or Mizrahi-Berk models.[56] Of these, the Herschel-Bulkley model (which combines power law and Bingham behavior) finds wide applicability to foodstuffs. It is described by

$$R = R_Y + K\dot{\gamma}^n \qquad (14)$$

Dervisoglu and Kokini[18] fitted data from both tomato ketchup and tomato paste to Eq. 14 and found yield stresses of 8 Pa and 43 Pa, respectively. In addition, the flow behavior index (0.26 to 0.38) was in broad agreement with other measured values. The Herschel-Bulkley model was used to relate yield stress to total solids content,[56] producing quadratic expressions for given cultivars of the form

$$\ln R_Y = k + k'(TS) + k''(TS)^2 \qquad (15)$$

where the coefficients are cultivar specific.

Another technique for determining yield stress is the stress relaxation method, which uses a rotational viscometer operated at low shear rate to record the shear stress at which no stress relaxation occurs when the shear rate is reduced to zero. Although this measures R_Y directly, great care is required to obtain reliable results.[56] Tanglertpaibul and Rao[61] used a stress relaxation method to measure the yield stress of tomato concentrates in the concentration range 9 to 14% total solids and found that the value of R_Y

increased with solids content and with the use of larger pulp finisher screen sizes in the aperture range 0.508 to 1.143 mm. This is in contrast with the apparent viscosity that was a maximum at an intermediate finisher screen size of 0.686 mm.

The foregoing models all assume that the behavior of the sample is unaffected by time. However, the rheological behavior of some foods is influenced by sample history. For example, the length of time for which a material has been subject to shear may determine the consistency of the fluid. Thixotropy is characterized by a decrease in apparent viscosity with prolonged shearing at a fixed shear rate; eventually, a minimum value of the apparent viscosity is reached at a given constant shear rate. This observed behavior should not be confused with the classic shear-thinning phenomenon described by the power law, although the two are closely linked. Evidence of slight thixotropy has been found with commercial ketchups,[6] but it is reported that the thixotropic component in tomato concentrates can be eliminated by shearing samples for a minute before taking measurements.[66] No conclusive measurements on the possible thixotropic behavior of tomato concentrates have been reported and comprehensive study of this area is needed.

VIII. OTHER QUALITY MEASURES

A. Flavor

Tomato flavor depends on the interaction between taste and aroma, and of these two factors taste is the more important. The characteristic sweet/sour taste of tomatoes depends principally on an interaction between the total sugars and titratable acidity[41] and the addition of reducing sugars and citric acid to fresh diced tomatoes significantly improves flavor.[42] The amino-nitrogen compounds, particularly glutamic acid, are taste enhancers,[41] and almost all tomato constituents make some contribution to taste.[64] One of the effects of heat processing tomato juice is an increase in acidity due to formation of pyrrolidone carboxylic acid, and it has been suggested that this compound may produce an unpleasant phenolic or bitter off-flavor.[47,58]

About 400 volatiles have been identified in tomato fruit; some of which are produced enzymatically when the fruit is comminuted.[33] Variations in volatile composition are found during ripening, between tomato varieties, and between field-grown and artificially grown tomatoes.[15] Many volatiles are lost by evaporation during the 'hot breaking', concentration, and heat pasteurization/sterilization of tomato juice for puree and paste, while many other compounds are formed at this stage.

Buttery and co-workers[10,11,12] carried out quantitative and sensory studies on the volatiles in tomato paste and identified those volatiles of significance to perceived odor. Capillary GLC and Capillary GLC-MS analysis of fresh tomato and tomato paste was used to identify volatiles and determine their concentration, and these concentrations were divided by their odor threshold concentrations in water to obtain odor units (U_0). The logarithm of odor units for each volatile was calculated and used to rank the volatiles in order of importance. All components in the paste at a concentration lower than their odor threshold ($\log U_0 < 0$) were considered unlikely to contribute significantly to fresh tomato or tomato paste odor. The major volatiles of fresh tomato are identified in Table 4, and the major volatiles of tomato paste in Table 5. In Table 5 two sets of concentrations are given in the first column; those in parentheses are the concentrations of each compound found in fresh tomato.

Examination of Tables 4 and 5 shows that the most dramatic changes in the odor compounds of fresh tomato brought about by processing to paste are the almost complete loss of *cis*-3 hexenal (which is the major contributor to fresh tomato aroma), the appearance of a large concentration of dimethyl sulfide, and an increase in the concentration of β-damascenone, which is a potent odorant. The compound *cis*-3-hexenal is known to be unstable to heat and to metal surfaces, while β-damascenone is likely to be formed from the hydrolysis of a glycoside.[10] Dimethyl sulfide is produced by thermal decomposition of the naturally occurring *S*-methyl methionine sulfonium salt.[10,11,69]

A synthetic tomato paste essence based on seven of the compounds identified in Table 4 was found by panel evaluation[10] to closely duplicate the odor of tomato paste; the composition of the essence is given in Table 6. According to the authors, methyl-butyric acid is usually considered an off-flavor, but in the right proportions and concentration it was found to be an essential part of the essence in giving a desirable aroma. Although dimethyl sulfide is absent from fresh tomato, using panel methods Guadagni and Meirs[25] found that levels of 0.5 to 2 ppm in tomato juice gave the most desirable tomato juice flavor. However, the desirable range of dimethyl sulfide may be higher for tomato paste. Assuming the sole source of dimethyl sulfide to be the *S*-methyl methionine sulfonium salt, Buttery et al.[10] estimated that the potential upper limit to dimethyl sulfide in tomato paste was 16 to 35 ppm. Levels of 0.8 to 10 ppm were found in a range of commercial tomato pastes with 28 to 30% total solids, with 2 ppm dimethyl sulfide being representative. While thermal decomposition of the *S*-methyl methionine sulfonium salt is most likely to occur during 'hot breaking' (in the hot first effect of a multiple-effect evaporator system) much of the dimethyl sulfide produced would be lost by steam volatilization.

Whereas volatile components are recovered from the vapor produced during the concentration of fruit juices,[8] the retention of aroma and flavor is much more critical than it is with tomato juice,[49] and it is not usual to recover volatile aromas during tomato processing.[5] However, a recently developed evaporator, built by Manzini Comaco, Italy, integrates juice preparation, 'hot breaking', and concentration into a single automatic line. Known as the MHV, the system collects volatile flavor components that might otherwise be lost by evaporation and adds them back to the tomato paste prior to packaging.[3]

B. Sensory Analysis

In tomato paste and puree there should be an absence of foreign and abnormal flavors and odors. Off-flavors may typically be

TABLE 4
The Major Volatiles in Fresh Tomato. Concentrations are Expressed as Parts (ml) of Compound per 10^9 (U.S. Billion) Parts of Tomato Paste or Tomato

Compound	Concentration (ppb)	Odor threshold in water (ppb)	log Odor Units
cis-3-hexenal	12000	0.25	4.7
β-Ionone	4	0.007	2.8
Hexanal	3100	4.5	2.8
β-Damascenone	1	0.002	2.7
1-Penten-3-one	520	1	2.7
3-Methylbutanal	27	0.2	2.1
Furaneol	700	31 (at pH 4.5)	1.4 (at pH 4.5)
Trans-2-hexenal	270	17	1.2
2-Isobutylthiazole	36	3.5	1.0

After Buttery et al.[10,11,12]

TABLE 5
The Major Volatiles in Tomato Paste. Concentrations Are Expressed as Parts (ml) of Compound per 109 (U.S. Billion) Parts of Tomato Paste or Tomato

Compound	Concentration (ppb)	Odor threshold in water (ppb)	log Odor Units
Dimethyl sulphide	2000 (0)	0.3	3.8
β-Damascenone	14 (1)	0.002	3.8
1-Octen-3-one	2	0.005	2.6
β-Ionone	2 (4)	0.007	2.5
Dimethyl trisulphide	2	0.01	2.3
3-Methylbutanal	24 (27)	0.2	2.1
Furaneol	1000 (700)	31 (at pH 4.5)	1.5 (at pH 4.5)
1-Nitro-2-phenylethane	66 (17)	2	1.5
Eugenol	100 (unknown)	6	1.2
Methional	3 (0)	0.2	1.2
3-Methylbutyric acid	2000 (200)	250	0.9
6-Methyl-5-hepten-2-one	370 (130)	50	0.87
Phenylacetaldehyde	18 (15)	4	0.65
Linalool	20 (2)	6	0.5
cis-3-hexenal	0.7 (12000)	0.25	0.4
Hexanal	8 (3100)	4.5	0.3
2-Isobutylthiazole	5 (36)	3.5	0.16
1-Penten-3-one	1 (520)	1	0
2-Phenylethanol	1000 (1900)	1100	–0.04

After Buttery et al.[10,11,12]

TABLE 6
A Synthetic Tomato Paste 'Essence'[10]

Compound	Proportion	ppb of compound in water	ppb of compound in tomato paste
Dimethyl sulphide	140	2000 (2 ppm)	2000
β-Damascenone	1.0	14.3	14
3-Methylbutanal	1.7	24.3	24
1-Nitro-2-phenylethane	5.0	71.4	66
Eugenol	7.1	101.4	100
Methional	2.1	3	3
3-Methylbutyric acid	140	2000	2000

described as 'bitter', 'caramelized', 'cardboardy', or 'metallic'.[55] Flavor is best judged against an approved standard and the paste or puree should have a 'clean' flavor, characteristic of concentrated ripe tomatoes.[22] The USDA Standard (1977) for grades of tomato paste allocates 50 score points each to the factors of 'color' and 'defects', giving a total of 100 points, but does not allocate points to samples for the attribute of 'flavor and odor'. Rather, there are three classifications of 'flavor and odor', and these are 'good', 'fairly good', and 'off' based on sensory assessment of both undiluted samples and samples diluted to 8 to 9% NTSS.[23] The three classifications of 'flavor and odor' are defined as follows:[23]

1. 'Good flavor and odor' means a distinct tomato paste flavor characteristic

of ripe, good-quality tomatoes and inclusive of any optional ingredient that may have been added. Such flavor and odor may be no more than slightly affected, by any one or combination of the following: stems, sepals, leaves, crushed seeds, cores; by immature, soured, or overripe tomatoes; from the effects of unsatisfactory preparation, processing, or storage; or from any other factor not specifically mentioned.
2. 'Fairly good flavor and odor' means a characteristic tomato paste flavor and inclusive of any optional ingredient that may have been added. Such flavor and odor may be affected, but not to any serious degree, by any one or combination of the following: stems, sepals, leaves, crushed seeds, cores; by immature, soured, or overripe tomatoes; from the effects of unsatisfactory preparation, processing, or storage; or from any other factor not specifically mentioned.
3. 'Off flavor and odor' means tomato paste flavor that fails to meet the requirements of 'fairly good flavor and odor' or that possesses a flavor and/or odor that is seriously objectionable.

Flavor and odor can be evaluated by taste panel using one or more of the following types of test:[23]

1. Paired comparison test
2. Triangle test
3. Dilution test
4. Ranking test
5. Numerical scoring test
6. The flavor profile method

In the paired comparison test the judges are asked to pick the sample with the better flavor from two unknown samples. The triangle test uses three samples, two of which are identical, and the judges are asked if there is a difference among the three. This test is useful for determining small flavor differences between samples. The dilution test may be used to determine the impact on flavor of compounds, such as flavorings and pesticides, provided these compounds are at levels exceeding their threshold values. The ranking test requires that judges rank samples in order of a specified attribute, such as flavor intensity, and is useful for routine quality control purposes. The flavor profile method is based on the recognition, description, and comparison of aroma and flavor by a trained panel of 4 to 6 judges,[17] but little use has been made of this method in tomato processing.[23] The numerical scoring test is used most frequently used in commercial practice and requires a trained panel of judges.

Poretta et al.[53] attempted to develop an objective method based on physical and chemical parameters for the quality evaluation of tomato pulp as a substitute for sensory assessment. This involved a search for the most significant correlations among some general sensory attributes and physical/chemical properties. The general sensory attributes were numerically scored as follows:

1. Acidity (1 = not sour at all; 9 = sour)
2. Natural taste (1 = taste very similar to the fresh one; 9 = taste very different from the fresh one)
3. Color (homogeneity of redness) (1 = very heterogeneous; 9 = fully homogeneous)
4. Viscosity (1 = solid phase completely separated from the liquid phase; 9 = very consistent product)

A significant correlation between pH and 'naturalness' emerged from this work.[53] Unusually, a significant correlation was also found between the sensory attributes of 'naturalness' and 'acidity' that suggests that care should be exercised in the choice of sensory attributes when carrying out panel evaluations.

C. Howard Mould Count

According to Gould,[23] a limited amount of mold growth occurs on sound tomatoes that breaks down the tomato tissue, producing a rot. The presence of large numbers of mold filaments in puree therefore is taken to mean that insufficient care has been taken by the manufacturer to maintain equipment in a clean condition or to reject, sort, and trim moldy raw material. The recognized method of counting mold filaments in tomato paste and puree, the Howard Mold count, is given in AOAC Method Number 965.41.[4] In this method, the paste or puree is diluted with water to give a refractive index at 20°C of 1.3448 to 1.3454 (about 9% soluble solids), and a sample is sandwiched between a slide and cover slip. With a 90 to 125 × microscope the mold filaments in a 1.5-square-mm field (diameter of 1.382 mm) are counted. At least 25 representative fields are examined per mount and two or more mounts are examined. A positive field is one in which:

1. A single filament exceeds 1/6 of the field diameter
2. A filament plus the length of its branches exceeds 1/6 of the field diameter
3. An aggregate of not more than three filaments exceeds 1/6 of the field diameter

The Howard Mold count is the percentage of fields found positive. Various standards have been proposed for the maximum Howard Mold count in tomato paste and puree, with the U.S. having the strictest standard as shown in Table 7.

It has been recognized by the U.S. Food and Drug Administration (FDA) that homogenization and milling of tomato products gives higher Howard Mold counts such that the USDA Standard may be exceeded and defect action levels have been adjusted accordingly.[67]

D. Rot Fragments

Rot fragments are defined as particles of tomato tissue with one or more mold filaments attached and are reported as the number of rot fragments per gram of product. The procedure for Rot Fragment Count is given in AOAC Method Number 952.23.[4]

E. Fly Eggs and Larvae

Small flies of the species *Drosophila*, particularly *Drosophila melanogaster*, are serious pests to the tomato producer, who deposit their eggs on fresh growth cracks in sound tomatoes and in cracks arising from the picking operation. The eggs are secured to the tomato by an adhesive substance and

TABLE 7
The Maximum Howard Mould Count Permitted by Various Standards in Tomato Paste and Puree[22,23,36,55]

Standard	Howard Mold count-maximum positive fields
FMF Trade Specification	50%
USDA	40%
CIPC 'Standard' quality	60%
CIPC 'Extra' quality	40%
EC 'Standard' quality	80%
EC 'Extra' quality	50%

are very difficult to remove. Some eggs and larvae may find their way into processed tomato products and in the U.S. tolerances for the number of *Drosophila* eggs and larvae in various processed tomato products have been set by the FDA, as shown in Table 8.

F. Insect Fragments

The Wildman trap flask method[4] and a wide field microscope are used to determine insect fragments in 100-g samples of tomato paste or 200-g samples of tomato puree.

G. Vitamins and Minerals

Tomatoes are an important source of vitamin A (in the form of carotene), vitamin C, and minerals (such as potassium and iron) in the diet because of the quantities of fresh tomatoes and processed tomato products consumed. The nutritional value of tomato products depends on processing conditions because the vitamins, particularly vitamin C, are susceptible to destruction by oxidation during processing and storage. However it is not often required to include an analysis for vitamin C when testing samples unless it is intended to use the pulp for juice or beverage production.

IX. CONCLUSION

There is no world-wide standard for the quality and composition of tomato concentrates, and there are considerable differences between the standards that are currently in use. Indeed, there are no agreed definitions of what constitutes tomato paste, pulp, puree, and concentrate. This, together with the absence of standardization of methods and instruments to define tomato paste quality, and insufficient reliability in the techniques and methods that are used, has been the main cause of disputes between companies producing tomato products. It is questionable whether the legislation on quality has kept pace with current industrial practice and this had led, for example, in the U.K., to the gaps in legislation being filled by codes of practice.

The main quality parameters of tomato puree and paste are color, consistency (and serum separation), and flavor. Despite the development in recent years that means that color can now be measured objectively with considerable precision, for example, by using the Judd-Hunter L, a, and b values, there is currently no standard method used across Europe for the measurement of the color of tomato concentrates, and no standard color requirements (e.g., L a b values) for tomato concentrates. A suitable 'hitching post' standard has been established only relatively recently and the recommended solids level at which measurements should be made, and which affects considerably measured color values, differs across the world. There is now sufficient data available to adopt a European-wide, if not world-wide, standard concentration for color measurements. Further, the adoption of minimum Judd-Hunter values of $L = 25$ and $a/b = 2.3$, as suggested by Brimelow,[9] is long overdue.

TABLE 8
FDA Defect Action Level for Drosophila Eggs and Larvae[23]

Product	Sample size (g)	Number of eggs and larvae
Tomato Puree	100	20 eggs
Tomato Puree	100	10 eggs + 1 or 2 larvae
Tomato Paste	100	30 eggs
Tomato Paste	100	15 eggs + 1 or 2 larvae

Consistency is generally measured empirically and the Bostwick viscometer, although widely used in industry, suffers from being limited to concentrates below 15% total solids, from an absence of industry-wide standards, and from disagreement over the solids level at which the measurements should be made. Serum separation tends to be measured by rather arbitrary methods. There has been much effort to determine the rheological behavior of tomato juice, serum, and concentrates. The power law has been found to be widely applicable and concentrates display considerable shear thinning. However, there is less agreement about the dependence of consistency coefficient and flow behavior index on temperature and concentration. Far less effort has been expended on other rheological characteristics, particularly time-dependant thixotropy. The lack of such data, particularly in view of the consequences of time-dependency for processing, needs urgent attention. Particularly disappointing is the lack of success in relating this rheological understanding to the commonly used empirical tests such as consistency measurements. More comprehensive studies are required to correlate Bostwick measurements with conventional rheological data over a wider range of concentrations than has been the case to date. Rheological measurements are becoming increasingly sophisticated, and studies are needed to determine whether empirical measurements are always an adequate guide to quality. More work is required on the temperature and concentration dependence of rheological parameters (consistency coefficient, flow index, yield stress) to remove the current uncertainty in this area; greater attention should be paid to concentrations above the normal range of 12 to 15% NTSS.

There has been considerable success with attempts to identify the volatiles responsible for flavor and odor and to reproduce these synthetically. However, only recently have any attempts been made to recover volatile components during the concentration of tomato juice and add them back to concentrated products prior to packaging. Flavor tends to be measured by taste panel methods, although little use has been made of the flavor profile method based on the recognition, description, and comparison of aroma and flavor by a trained panel. Numerical scoring tests are used more frequently. Efforts to develop objective methods as a substitute for sensory assessment have involved correlating general sensory attributes and physical/chemical properties and, for example, have highlighted a significant correlation between pH and 'naturalness'.

REFERENCES

1. Anon., Swedish Standard SS 01 91 03, 1982.
2. Anon., MVR-is it worth it?, *Food Eng. Int.*, 1987; **12(2):** 39–40, 42.
3. Anon., Combination process cuts costs, *Food Eng. Int.*, 1993; **18(1):** 11–12.
4. A.O.A.C., *Official Methods of Analysis of the Association of Official Analytical Chemists*, 16th ed., Arlington, Virginia: A.O.A.C., 1995.
5. Arthey, D. and Ashurst, P. R., Eds., *Fruit Processing*, London: Blackie Academic and Professional, 1996, 191–195.
6. Autio, K. and Houska, M., Measurement of flow curves for model liquids and real food systems with two commercial viscometers, *J. Food Sci.*, 1991; **55:** 554–555.
7. Banwart, G. J., *Modern Food Microbiology*, 2nd ed., New York: Van Nostrand Reinhold, 1989.
8. Brennan, J. G., Butters, J. R., Cowell, N. D., and Lilley, A. E. V., *Food Engineering Operations*, 3rd ed., London: Elsevier, 1990, 346–347.
9. Brimelow, C. J. B., Measurement of tomato paste color: investigation of some method variables. In: Jowitt, R. et al., Eds., *Physical Properties of Foods*, London: Elsevier, 1987, 295–317.

10. Buttery, R. G., Teranishi, R., Ling, L. C., and Turnbaugh, J. G., Quantitative and sensory studies on tomato paste volatiles, *J. Agric. Food Chem.*, 1990; **38:** 336–340.

11. Buttery, R. G., Teranishi, R., Flath, R. A., and Ling, L. C., Identification of additional tomato paste volatiles, *J. Agric. Food Chem.*, 1990; **38:** 792–795.

12. Buttery, R. G., Takeoka, G. R., and Ling, L. C., Furaneol: odor threshold and importance to tomato aroma, *J. Agric. Food Chem.*, 1995; **43:** 1638–1640.

13. Caradec, P. L. and Nelson, P. E., Effect of temperature on the serum viscosity of tomato juice, *J. Food Sci.*, 1985; **50:** 1497–1498.

14. Caradec, P. L., Nelson, P. E., and Takada, N., Tomato products: a new serum separation measurement, *J. Food Sci.*, 1985; **50:** 1493–1494.

15. Dalal, K. B., Olson, L. E., Yu, M. H., and Salunkhe, D. K., Gas chromatography of the field, glass-greenhouse grown, and artificially ripened tomatoes, *Phytochem.*, 1967; **6:** 155–157.

16. Dale, M. C., Okos, M. R., and Nelson, P. E., Concentration of tomato products: analysis of energy saving process alternatives, *J. Food Sci.*, 1982; **47:** 1853–1858.

17. deMan, J. M., *Principles of Food Chemistry*, 2nd ed., New York: Van Nostrand Reinhold, 1990.

18. Dervisoglu, M. and Kokini, J. L., Steady shear rheology and fluid mechanics of four semi-solid foods, *J. Food Sci.*, 1886; **51:** 541–546.

19. Filkova, J., Lawal, A., Koziskova, B., and Majumdar, A. S., Heat transfer to a power law fluid in tube flow: numerical and experimental studies, *J. Food Eng.*, 1987; **6:** 143–151.

20. Fito, P. J., Clemente, G., and Sanz, F. J., Rheological behavior of tomato concentrate, *J. Food Eng.*, 1983; **2:** 51–62.

21. Francis, F. J., Food colorimetry: measurement and interpretation. In: Jowitt, R. et al., Eds., *Physical Properties of Foods*, London: Elsevier, 1987, 237–249.

22. Goose, P. and Binstead, R., *Tomato Paste and other Tomato Products*, 2nd ed., London: Food Trade Press Ltd., 1973.

23. Gould, W. A., *Tomato Production, Processing and Quality Evaluation*, 2nd ed., Westport, Connecticut: AVI Publishing, 1983.

24. Gould, W. A., *Tomato Production, Processing and Technology*, Baltimore: CTI Publishing, 1992.

25. Guadigni, D. G. and Miers, J. C., Statistical relationship between methyl sulphide content and aroma intensity in canned tomato juice, *Food Technology*, 1969; **23:** 101–103.

26. Hand, D. B., Moyer, J. C., Ransford, J. R., Hening, J. C., and Whittenberger, R. T., Effect of processing conditions on the viscosity of tomato juices, *Food Technology*, 1955; **9:** 228–235.

27. Heinz U.K., *Cold break tomato paste specification bulletin*, 1990.

28. Hewitt J. D. and Garvey, T. C., In: Nevins, D. J. and Jones, R. A, Eds., *Tomato Biotechnology*, New York: Liss, 1987.

29. Hutchings, J. B., *Food Color and Appearance*, London: Blackie Academic and Professional, 1994.

30. Jay, J. M., *Modern Food Microbiology*, 3rd ed., New York: Van Nostrand Reinhold, 1986, 250.

31. Jinescu, V. V., The rheology of suspensions, *Int. Chem. Eng.*, 1974; **14:** 397–420.

32. Kattan, A. A., Ogle, W. L., and Kramer, A., *Food Technology*, 1956; **10:** 68.

33. Kazeniac, S. J. and Hall, R. M., Flavor chemistry of tomato volatiles, *J. Food Sci.*, 1970; **35:** 519–530.

34. Kent, M., Collaborative measurements on the color of light-scattering foodstuffs. In: Jowitt, R. et al., Eds., *Physical Properties of Foods*, London: Elsevier, 1987, 277–294.

35. Kent, M. and Poretta, S., Standardization of the measurement of tomato paste color using a new color reference tile, *Industria Conserve*, 1990; **65:** 9–16.

36. Kirk, R. S. and Sawyer, R., *Pearson's Composition and Analysis of Foods*, 9th ed., Longman, 1991, 253–256.