Abstract The organoleptic quality of fresh market tomato can be described by a set of attributes, including fruit appearance, taste, aroma and texture. Sensory analysis is the most-valid method to study organoleptic characteristics, particularly aroma and texture. A range of 144 recombinant inbred lines of tomato derived from a cross between a cherry tomato line and a large-fruited line was evaluated by descriptive sensory profiling. Taste was analyzed through sweetness and sourness, and aroma was analyzed through the overall aroma intensity, together with candy, lemon, citrus-fruit and pharmaceutical aroma. Texture was characterized by firmness, meltiness, mealiness, juiciness and difficulty to swallow the skin. A wide range of overall variation was shown for all the attributes and significant differences among genotypes were detected. The overall aroma intensity was positively correlated with sweetness and sourness, as well as with lemon, candy and citrus fruit aromas. It was negatively correlated with mealiness. Sweetness and sourness were negatively correlated together. Molecular markers were used to map quantitative trait loci (QTLs) for each sensory attribute. One to five QTLs were detected, by simple and composite interval mapping, per attribute. The percentage of phenotypic variation explained ranged from 9% to 45% per QTL. Clusters of QTLs were observed on chromosomes 2 and 9, involving QTLs for aroma, taste and texture attributes. Most of the favorable alleles came from the cherry tomato parent, showing the potential usefulness of this line for tomato organoleptic quality improvement.

Keywords Tomato · Sensory analysis · Organoleptic quality · QTL · Composite interval mapping

Introduction

Since the 1970s, the yield and the yield stability of fresh market tomato has increased, together with adaptation to glasshouse conditions. Tomato fruit quality for the fresh market has also been strongly improved for 30 years. Fruit appearance and homogeneity were first improved. More recently, firmness and long shelf life, required for shipping to distant markets, retained the attention of fresh market breeders (Tigchelaar 1986). With the availability of tomato all year round and with the spread of long shelf life varieties, consumers began to complain about tomato flavor. Such criticisms seemed common to many countries such as the USA (Kader et al. 1977), Australia (Ratanachinakorn et al. 1997), the Netherlands (Janse and Schols 1995) and France (Decoene 1995). Consumers frequently associate recent varieties with a lack of flavor, although such an association could not be proven (Bruhn et al. 1991). Modifications in texture, mainly the increase in firmness observed in the modern varieties, are probably also responsible for consumer complaints. Taste-panel studies have shown that sweetness and sourness were the major determinants of tomato flavor preference (Stevens et al. 1977). Appearance, color, aroma, and texture are also major components of organoleptic quality.

Sensory analysis is the most-valid method to study organoleptic characteristics and has recently been used for the taste description of different fruits such as peach (Esti et al. 1997) or blackcurrant (Brennan et al. 1997). In tomato, Hobson et al. (1990) characterized the flavor of different tomato varieties by sensory profiling. They found strong differences between the flavor of cherry tomato and large-fruited tomatoes, the former being much
The flavor of tomato was found to be influenced not only by the variety and nutritional regime of the plants (Hobson and Bedford 1989; Petersen et al. 1998), but also by the stage of ripening when picking fruit (Kader et al. 1977, 1978) and by post-harvest storage conditions (Ratanachinakorn et al. 1997). Kader et al. (1978) noted a decrease in the flavor of green-harvested or refrigerated fruits. Sensory analysis was also used to assay the perception of transgenic fruits with reduced polygalacturonase activity (Sozzi Quiroga and Fraschina 1997). Studies were performed to identify associations between fruit composition or physical characteristics and sensory traits (Baldwin et al. 1998). Sweetness and sourness were commonly found associated with sugar- and acid-content, respectively. Sugar- and organic acid-content, together with the sugar/acid ratio, were the major chemical compounds of consumer preference (Stevens 1979). Apparently the proper balance of these compounds is required to give optimal flavor, and a given sugar level corresponds to an optimal acid content (Malundo et al. 1995). Volatile compounds contribute to the tomato overall aroma intensity and numerous studies were devoted to identify the major constituents responsible for tomato aroma (Langlois et al. 1996; Baldwin et al. 1998; Krumbein and Auerswald 1998). Sweetness, sourness and overall aroma intensity are the three most-studied attributes (Jones and Scott 1984; Kader et al. 1977).

Most of the traits of interest, including the sensory attributes, have a continuous variation, strongly influenced by environmental conditions. The genetic variation of such traits has been attributed to the joint action of many genes. With the development of molecular markers, a number of saturated genetic maps have been constructed in plant species, which has allowed the location of loci (named QTLs for quantitative trait loci) controlling quantitative trait variation. Since the pioneer work of Paterson et al. (1988), QTL analysis has been applied to numerous species and traits. For most of these traits, a limited number of QTLs were detected, explaining a large part of the variation. In tomato, most of the studies concerned yield and quality traits (pH, soluble-solids content and fruit weight) of processing tomato (Paterson et al. 1988, 1991; Eshed and Zamir 1995), but also horticultural traits (Grandillo and Tanksley 1996; Bernacchi and Tanksley 1997; Fulton et al. 1997), as well as adaptation to abiotic stress (Foolad et al. 1997). Molecular markers are highly efficient for the evaluation of exotic germplasm (Tanksley and McCouch 1997), particularly in tomato where most of the molecular variability was found between related wild species rather than within the cultivated species. QTLs were detected with most of the species related to Lycopersicon esculentum (see Chen et al. 1999 for a recent review). QTL analysis was also applied to quality traits in peach (Dirlewanger et al. 1999), cucumber (Kennard and Havey 1995) and lemon (Fang et al. 1997). A recent publication reported the identification of QTLs associated with sensory preference in sweet corn (Azanza et al. 1996).

The purpose of the present paper is to study the inheritance of sensory attributes related to the fresh market tomato organoleptic quality and to describe the QTLs affecting these traits. We selected a remarkable cherry tomato line (Cervil) with strong aroma intensity, which was crossed to a large-fruit line. A segregating population was derived and assessed by a trained panel for 12 sensory attributes. The paper describes: (1) the analysis of sensory attributes in a large population size, (2) the study of the correlations between the various attributes, and (3) the location and characterization of QTLs.

Materials and methods

Mapping population

The studied population comprises 144 recombinant inbred F7 lines (RILs) derived from the cross between a cherry tomato L. esculentum var. cerasiforme (Cervil, coded C) and a round larger-fruited tomato line (Levovil, coded L). The VILMORIN seed company provided both parental lines. The plant materials are described in Saliba-Colombani et al. (2000a).

Glasshouse trial

The 144 RILs were grown in a heated glasshouse during a spring crop (January–July) in a fully randomized trial. The two parental lines were each represented by three plots and the F7 hybrid by nine plots. Each plot consisted of a single row of six plants. Ripe fruits were harvested daily during 6 weeks at the red stage, 1 day before fruit evaluation. Fruits with a homogeneous color were selected for sensory evaluation. Special care was taken to provide panelists with fruits at the same ripening stage.

Sensory profiling

Sensory analysis was performed with a panel of 54 trained panelists. Judges were grouped into four panels. Three were composed of seed company employees (CLAUSE, VILMORIN, TEZIER), with 20, 8 and 8 panelists, respectively. The fourth panel (DIJON) was composed of 18 volunteers already trained for sensory analysis with other products. This panel performed three assays per week, while the other three performed only one. Each panel was drawn by a leader. Panelists were trained during 13 assays before the experiment began. Attributes were selected after 2 years of sensory analyses with related tomato material. Taste attributes were sweetness (SWE) and sourness (SOU). Aroma attributes were overall aroma intensity (INT), candy aroma (CAN), lemon aroma (LEM), citrus-fruit (other than lemon) aroma (CIT) and pharmaceutical aroma (PHA). Texture attributes were flesh firmness (FIT), mealinness (MEA), meltiness (MEL), juiciness (JUI) and embarrassed skin (SKI). Flavor descriptors were defined by reference solutions in mineral water: glucose (6 g/l) and fructose (6 g/l) for sweetness, citric acid (1 g/l) for sourness, lemon juice (30 ml/l) for lemon aroma, candy (40 g ground/l) for candy aroma, juice from half a pomelo and one orange for citrus-fruit aroma, and guaiacol (10 µl/l) for pharmaceutical aroma. Aroma intensity corresponded to the general impression of aroma before swallowing. Definition of texture attributes were as follow: mealinness – the sample is dry, mealy, powdery and non-sticky, saliva is necessary to swallow it; meltiness – the sample turns from solid to liquid easily, without chewing; juiciness – the sample liberates some juice when chewed, this juice comes from flesh and gel; firmness – the sample resists when chewed; embarrassing skin – the skin is difficult to swallow and tends to stay in the mouth. Panelists were instructed to cleanse their palate with bread and mineral water bet-