THE EFFECT OF FROST ON THE COMPOSITION OF SHAMOUTI ORANGES[1])

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Following some fifteen years with consistently mild winters, the frosts which occured in January 1949 and again early in 1950, resulted in considerable injury to part of the Israel orange crop. Definite external signs of frost damage were generally indiscernible on the fruit shortly after the frost, but if the fruit was cut open a few days later, white hesperidin crystals could be seen on the segment walls and the fruit had a slight off taste. Later, air spaces appeared between the segments, the fruit-pulp became rather dry, in the fashion of overripe oranges, while the off-taste became more pronounced.

Although frost damage occurs quite frequently in most cirturs-growing areas of the world, the literature on the subject is rather limited. The effect of frost damage upon citrus fruits was studied in California in conection with the frost of 1913 (8,12) and various aspects of frost injury formed the subject of subsequent investigations (1,2,4,6) Changes occurring in frost-damaged fruit, such as thickening of the peel, lowering of the juice content and a corresponding decrease in specific gravity, were first described by *Webber* and his coworkers. *Bartholomew* et al. observed a partial recovery of Valencia oranges which were damaged by frost while still immature. There appears to exist no report on the suitability of frost-damaged fruit for the products industry.

In consideration of the fact that export of even slightly damaged fruit might do harm to the good reputation of Israel oranges, it was important to find an other outlet for such fruit. This study was therefore primarily concerned with those aspects of frost injury which affect the fitness of the fruit for industrial utilization. The relative merits of leaving frost-damaged fruit on the tree, as against its immediate picking and storage were also investigated.

In 1949 it was not possible to begin observations until about three weeks after the onset of the frost; in the following year, however, the study was taken up within a few days of the frost.

It has been observed (11) that frost damage in orange groves sets in when temperature drops below -3°C. Such low temperatures were recorded by Mendel (7) during two cold spells in the winter of 1950. These data were obtained at the meteorological station of the Institute which is located on top of a hill, and also in a low-lying grove in the neighbourhood of the Rehovot Station (Table 1, p. 110)[2]). There is reason to believe that in the low-lying grove fruit was damaged prior to the date of the first frost record (28—29 January), since hesperidin crystals which are reported to form only some five to ten days after frost, were detected as early as February 1. No detailed records of grove temperatures are available for the 1949 freeze, but it is thought that frost damage occured about January 10.

1) Abridged translation from Hebrew.

2) Page numbers in parentheses refer to the Hebrew text.

PLAN AND METHODS

All the observations were conducted in the low-lying Rehovot-Ness Ziona area which was, on the whole, badly affected by the frost. Since no orange grove could be found in which only part of the trees had been damaged, comparisons had to be based on fruit taken from different orchards. Samples of damaged fruit were primarily derived from grove B (Table 2, p. 111); while grove A, about one kilometer away, which is located some 30 meters higher than grove B and which escaped injury, provided controls. The lowest temperature recorded in this control grove was -2.5°C. The fact that no frost injury occurred is also supported by the comparison of fruit composition with that consistently ascertained for the same grove in the course of five preceeding seasons (9). Samples from two additional groves (C and D) were included for comparison. Each sample consisted of about 150 fruits picked at random from 5 to 10 trees. Somewhat larger samples were taken for the storage experiments, to compensate for possible wastage, and were made up of fruits weighed individually and wrapped in diphenyl paper. After a period of storage at room temperature, the fruit was re-weighed before analysis and spoiled fruit was discarded. The juice was reamed by means of an electric reamer (Hobart) and sieved under light pressure, the residue being reported as "sieve residue". The methods of analysis and the assessment of "threshold bitterness" had been previously described (9, 10).

In the 1949 tests, the pulp which remained attached to the peel after reaming obscured the results of analysis and changes occuring in the peel could not be properly observed. In 1950 the pulp was therefore carefully removed from the albedo and was added to the sieve residue. This difference in procedure should be taken into account in comparing the results of peel analysis for the two years. The data for 1950 are also more conclusive due to the fact that sampling was begun at an earlier stage.

RESULTS

1. *Changes occurring in fruit retained on the tree* (Table 3, p. 112, 113).

One of the most striking changes in frost-damaged fruit concern specific gravity which went well below the values obtained for healthy fruit (9). Specific gravity decreased rapidly within a few days of the onset of the frost and continued to decrease during the subsequent weeks (Table 3, p. 112—113) (Fig. 1, p. 114). This decrease of specific gravity is accompanied by a steep decline in the juice content. Frost-injured oranges were also found to have a higher peel content due to increased peel thickness. In Fig. 2 (p. 114) juice and peel contents are expressed in terms of kilograms per ton of fruit, based on the weight of the fruit at the time of the first picking, in order to eliminate the effect of changes in the weight of fruit taking place on the tree or in storage. Analysis of sugars and total soluble solids gave similar values for healthy and frost-damaged fruit; but while the percentage of these components in healthy fruit continued to rise, during ripening, no such increase was noted in injured fruit.

In healthy fruit, the sugar content showed a continuous seasonal increase both in the juice and in the peel. In frost-injured fruit remaining on the tree there was no such increase in the juice, whereas an initial increase in the sugar content of the peel was followed by a gradual diminuation. Similarly, the content of total soluble solids showed an upward trend in the healthy, but not in the damaged oranges. The content of other components such as ascorbic and citric acids, pectin and essential oil was not affected by the frost.

As indicated by determinations of threshold bitterness (Table 4, p. 115), the juice of healthy fruit lost its bitterness in the course of ripening, while the bitterness of juice from frost-damaged fruit persisted throughout the period of observation. The bitterness of peel and of sieve residue also decreased more slowly in frost-damaged fruit.

2. *Changes in stored fruit* (Table 5 and 6, pp. 116, 117).

The changes in the composition of healthy oranges are slow and gradual both when the fruit is retained on the tree and when kept under normal storage conditions. The rapid changes in composition which take place in frost-damaged fruit retained on the tree, can also be slowed down or arrested, if the fruit is picked immediately and stored at room temperature. Thus, in storage, the loss of juice was considerably reduced, while bitterness disappeared somewhat more rapidly and sugar content retained higher values (Table 6, p. 117). The loss in weight of fruit during storage up to 25 days does not appear to be affected by frost.

3. *Suitability of frost-damaged fruit for different products.*

Three citrus products were prepared from frost-damaged fruit in order to determine the relative effect of bitterness—namely pasteurized juice, concentrate and marmelade In marmelade, the slighly bitter taste, reminiscent of bitter orange marmelade (*Citrus Aurantium L.*) was not unpleasant. The product had a good flavour and would, no doubt, be well received on the market. Pasteurized juice and concentrate from healthy and frost-damaged fruit are compared for threshold bitterness in Table 7 (p. 120). Pasteurized juice retained its bitterness after four months of storage. When, however, such juice was converted into a concentrate, the bitterness diminished rapidly, decreasing by about 90 per cent within 9 days, and within three weeks disappeared altogether. Subsequent dilution of the stored concentrate did not result in reappearance of bitterness. Data, as yet unpublished, indicate a similar trend in concentrates prepared from unripe fruit.

DISCUSSION

The loss of juice in Shamouti oranges due to frost damage was found to amount at times to as much as 30 per cent within a month. *Beecham* (2), who studied the effect of frost on other orange varieties in California and Florida, reported losses of only about 10 per cent. The reduction in juice content together with the increased thickness of the peel and the intrusion of air-spaces between the segments, are responsible for a decrease in specific gravity of the fruit. The decrease recorded there is of similar magnitude to that reported by *Thomas* et al. (12). Contrary to their findings, however, our results do not indicate any marked differences in juice composition between healthy and frost-damaged fruit.

During the period of study, there was no rise in the sugar content of the juice in ripening healthy fruit (Fig. 3 p. 119), and any percentage increase would seem to be due to water loss and not to actual accumulation of sugar. In frost-damaged fruit, on the other hand, since the decrease in juice content not accompanied by a rise in concentration, translocation rather than any process of water evaporation is indicated. The decrease in the sugar content of fruit could be due to different processes—such as increased respiration, transfer of carbohydrates back into the tree, or translocation of sugar to other fruit tissues. In view of the fact that the amount of carbohydrates in the whole fruit did not change appreciably, the last assumption appears to be the most probable. It is suggested that, as a result of frost damage, sugars pass from the interior towards the outer periphery of the fruit, where they may be utilized for the synthesis of more complex carbohydrates required for the building of additional peel tissues. According to *Young* (13), frost injury results in the loss of semi-permeability of the section membranes. This may enhance such movement of sugar solutions towards the fruit periphery. It is possible that the process of peel thickening resembles frost-induced tumor formation in succulent plants, as described by *Harvey* (5).

Frost damage limits considerably the marketability of the Shamouti oranges. *Shiftan* (11) suggested a manner of harvesting which would render part of the damaged crop exportable. Most of the frost-injured fruit would, nevertheless, have to be directed to industrial use. The present results show that such fruit is suited for the production of concentrates, since in these products bitterness is eliminated after a short period of storage.

Recovery of frost-damaged fruit on the tree, such as had been described in regard to Valencia oranges (1,6), was not observed in the case of Shamouti. It was ascertained on the contrary, that the damaged fruit continued to deteriorate. This difference in behaviour may be due to the fact that while the Valencia fruit was probably damaged by frost before reaching full maturity, the Shamouti oranges was already fully ripe before the frost set in.

The results of our storage experiments are at variance with the findings of *Bartholomew* et al. (1) and *Thomas* et al. (12), but it should be noted that in their investigations storage was only begun two to four weeks after the occurrence of frost. The present results show that if damaged fruit is harvested soon after the frost, there is little deterioration in storage. If extensive areas are damaged, so that the industry is unable to absorb the whole of the damaged crop, it may be worth while to harvest and store the fruit—notwithstanding the additional expense—in order to minimize losses due to rapid reduction in weight, changes in composition and premature fruit-drop.

SUMMARY

1. The composition and physical properties of Shamouti oranges damaged by the frosts of 1949 and 1950, were determined, with particular reference to suitability for industrial use. Damaged fruit retained on the tree was compared with similar stored fruit.
2. No external marks were detected on the injured fruit, but internal signs of damage were noted, such as air-spaces between the segments, dryness of the fruit pulp, hesperidin crystals on the segment walls, and thickening of the peel.
3. The specific gravity and the juice content of damaged oranges decreased while the weight of the peel and of the peel residue showed an increase. The content of total solids, of sugar, ascorbic acid and essential oil, and the pectin content of the peel, were not affected to any extent. The peel of frost-damaged fruit was found to contain less sugar than the peel of healthy fruit.
4. Juice from frost-damaged fruit tasted more bitter than that from healthy fruit. While the bitterness of healthy fruit disappeared fairly quickly in the course of ripening, this process was much slower in frost-injured fruit.
5. Sugar content increased during the ripening of healthy fruit, but not in frost-damaged fruit retained on the tree. The suger accumulation in healthy fruit appears to be due to transpiration ratherthan due to sugar synthesis.
6. In frost-damaged fruit, the sugar content is found to decrease in the juice, but not in the fruit as a whole. It is suggested that sugars are translocated from the inner pulp of the injured fruit to the rapidly thickening peel.
7. The harmful effects of frost damage are considerably lessened if the fruit is harvested straight away and stored at room temperature.
8. Frost-damaged fruit is better utilized for concentrates than for pasteurized juice, since in the former the bitter taste disappears within 2 to 3 weeks, while in the latter it persists for a long time.