The relationship between the anatomical structure of the tomato fruit pericarp (*Lycopersicon esculentum* Mill.) and its mechanical properties

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Abstract

The anatomical structure of the tomato (*Lycopersicon esculentum* Mill.) pericarp was studied in the fruits of five determinant field cultivars. The fruits of the examined cultivars differed in their mechanical properties. Fruits of cultivars which are firm and resistant to injury (Kecskemeti 886j-2, Campbell 28), moderately firm and resistant (Atma, Wenus) and soft, susceptible to injury (line No 155/84) were examined.

The pericarp of the cultivars which have fruits resistant to injury had an approx. 200 µm thick covering layer (epidermis plus cuticle plus hypodermis) whereas that of fruits susceptible to injury was only 100 µm thick. In the fruits resistant to injury the cuticle penetrated deeply into the hypodermis, the epidermal cells were flattened and the hypodermis was composed of 4-5 rows of cells. The tomato fruits resistant to injury had a thick cuticle layer on their tangential walls — whereas those more susceptible had a thick cuticle layer on these walls.

INTRODUCTION

The problem of firmness and resistance of tomato fruit to external injury has attracted the attention of breeders for many years. These traits determine the suitability of the cultivar for mechanical harvesting, long transport and extended storage. Until recently most authors studied the influence of various physiological and environmental factors on the mechanical properties of the fruits. They claimed that such factors as moisture, temperature, age and also morphological structure of the fruit influence its susceptibility to injury (Frazier and Bowers, 1938; Frazier, 1947; Reynard, 1951). It was proved, however, that firmness and resistance of tomato fruits also depend on the anatomical structure of their pericarp. Chebanu (1972) demonstrated that the

tomato fruit pericarp consists of 23-29 rows of cells. He noted a histological zonality in the pericarp of all the examined cultivars. He distinguished: an outer epidermis, parenchyma and an inner epidermis. On the basis of the size and shape of the parenchyma cells (in the mesocarp) Chebanu (1972) and Chu and Thompson (1972a) suggested distinguishing the following zones: a layer of hypodermis, a subhypodermal layer reaching to the peripheral vascular bundles and a layer extending from the vascular bundles to the cells of the inner epidermis.

Differences occurring in the anatomical structure of the fruits resistant and sensitive to injury were noted by several authors. Cotner et al. (1969) considered that fruits resistant to cracking have an epidermis built of elongated cells, while in the susceptible ones the epidermal cells are close to spherical in shape. Pearson (1970) called attention to the structure of the whole "covering layer" of the tomato fruit. He claimed that firm fruits have a covering layer consisting of epidermis, covered from outside with a thin layer of cuticle and 3-5 rows of hypodermal cells. The cuticle penetrates as far as to the second or third row of hypodermal cells which in shape and size resemble those of the epidermis. Soft fruits have a single-layered hypodermis composed of nearly spherical cells. The cell walls of the epidermis in these fruits are strongly cutinized. These observations were confirmed in later investigations by Hankinson and Roa (1979) and Pagalday (1984). However, Chu and Thompson (1972b, c) believe that the hypodermis of firm fruits has 1-2 rows of cells and that of the soft ones has 4-5 rows. Voisey et al. (1970) suggest that the susceptibility of tomato fruit to injury is connected with the elasticity of the epidermis, and not with its thickness. These authors and Lapushner et al. (1984) called attention to the differences in structure of the vascular bundles in fruits resistant and susceptible to injury. They claimed that the differences concerning absorption and distribution of water are important for the susceptibility of fruit to injury.

Since there is no unanimity in the views on the influence of the anatomical structure on tomato fruit firmness — a feature essential in processing and transport, it seemed interesting to investigate this problem on varieties cultivated in Poland.

MATERIAL AND METHODS

Five field determinant tomato cultivars differing in morphological traits (fruit size, shape, number of seed cavities and pericarp thickness) as well as in mechanical properties (firmness and resistance to external injury) were chosen. They were:

- firm and resistant to injury — Kecskemeti 886j-2, Campbell 28,
- medium firm and medium resistant — Atma, Wenus,
- soft, susceptible to injury — line No 155/84.

MEASUREMENT OF "COVERING LAYER" THICKNESS

The term skin is currently applied by breeders to the uppermost layers of tomato fruit. In order to avoid misunderstanding resulting from the botanical and colloquial designations for skin, in the present paper the name "covering layer" of the fruit is introduced, according to the suggestion of Pearson (1970). It comprises the cuticle, epidermis and hypodermis.

The thickness of the covering layer was studied during four seasons 1981-1984. Fifteen ripe, uniformly coloured fruits of each cultivar were taken for examination. An NV1 Zeiss light microscope was used. The methods of cutting and measuring followed those given by Braune et al. (1975). Measurements were made on unfixed preparations. Sections were taken from the pericarp at three places on the fruit:

- a — 1 cm from the end of the calycine depression (basin) in the proximal part of the fruit,
- b — in the middle part of the fruit,
- c — 1 cm from the trace of the carpel (distal part of the fruit).

The thickness of the covering layer was measured three times on each preparation, and the results are given as its mean thickness in the fruit.

OBSERVATIONS ON THE ANATOMICAL STRUCTURE OF THE EXTERNAL ROWS OF CELLS OF THE PERICARP

Sections for examination were taken from ripe tomato fruits at three sites similarly as for measurement of the covering layer. The material was fixed for 24 h in a chromacetoformalin mixture (CrAF 0.5%-2.0%) dehydrated, embedded in paraffin and cut into 12 μ m thick transverse and tangential sections. The preparations were stained in a 2.0% aqueous safranin solution for 4 h and counterstained with a 0.2% fast green alcohol solution. The preparations were inspected in a light microscope and microphotographs were taken.

RESULTS AND DISCUSSION

The covering layer was the thickest (180-200 μ m) in the cultivars Kecskemeti 886j-2 and Campbell 28, therefore in the firm ones resistant to external injury (Table 1). The fruits of the cultivars Atma and Wenus, moderately firm, had the moderately thick covering layer (125-140 μ m), whereas in the soft line, No 155/84, the covering layer was only 101-105 μ m thick. No significant differences were found in the thickness of the covering layer within each cultivar depending on the year. Therefore, it may be accepted that the thickness of the covering layer is a relatively constant trait characteristic for a given cultivar and does not vary markedly in response to environmental conditions. Our results support the results of Pearson (1970) who

Plate 1. Transverse sections through the pericarp of ripe tomato fruits (stained with safranin and fast green alcohol solution). Cultivars: 1. Campbell 28, 2. Kecskemeti 886j-2, 3. Atma, 4. Wenus, 5. Line No 155/84. Magn.

Plate 2. Tangential sections through the epidermis of ripe tomato fruits; other details as in Plate 1.
Magn.

Table 1

Thickness of covering layer (cuticle, epidermis and hypodermis) of tomato fruits (μm). Averages for 15 fruits

Year	Cultivar				
	Kecskemeti 886j-2	Campbell 28	Atma	Wenus	Line No 155/84
1981	199.8	182.2	136.2	128.4	102.0
1982	197.6	185.2	139.4	127.5	101.0
1983	192.5	182.9	138.2	126.1	104.7
1984	194.5	179.6	130.6	129.4	102.6
Averages for cultivars	196.1 ^c	182.4 ^c	136.1 ^b	127.8 ^b	102.6 ^a

The averages marked with the same letters fo not differ significantly at $P = 0.05$ (in Duncan test).

suggested that fruits with good mechanical qualities are those with a thick hypodermic layer.

Microscopic observations of the superficial rows of pericarp cells in the five studied cultivars showed marked differences among them (Plate 1). The firm cultivar Campbell 28 (Plate 1, Fig. 1) had a moderately thick cuticle which penetrated as deep as to the third row of hypodermal cells. The epidermal cells were flattened and of similar dimensions. The hypodermis consisted of five rows of flattened cells tightly arranged and passing gradually into larger parenchyma cells.

The fruits of the cultivar Kecskemeti 886j-2 had a pericarp with a similar structure (Plate 1, Fig. 2). Only mesocarp parenchyma consisted of more flattened, larger and less regular cells than in the fruits of Campbell 28.

In the fruits of cultivar Atma (Plate 1, Fig. 3) the epidermal cells were more rounded and larger than in the two preceding cultivars. The cuticle penetrated to the second of the three hypodermal rows. The first row of hypodermis had flattened cells, the next two consisted of more flattened, tightly packed cells. The change in their size in the transition to parenchyma was more drastic. Parenchyma cells were only slightly flattened.

In the cultivar Wenus (Plate 1, Fig. 4) the cells of the epidermic were only slightly flattened. The cuticle penetrated to the second cell row of the three-rowed hypodermis. The cells of the later were arranged irregularly. There was a distinctly outlined border between the hypodermis and the mesocarp parenchyma cells. The parenchyma was built of rather irregular loosely lying cells, only slightly flattened.

The fruits of line No 155/84 (Plate 1, Fig. 5) had a thick cuticle layer penetrating only among the side walls of the epidermis. The cells of the later were almost spherical. The hypodermis consisted only 1-2 rows of cells. A distinct transition was distinguishable between the hypodermis and mesocarp parenchyma. This last tissue consisted of loosely arranged cells.

Tangential sections through the epidermis (Plate 2, Table 2) showed that fruits of the cultivars resistant to injury—Campbell 28 (Fig. 1) and Kecskemeti 886j-2 (Fig. 2) had an epidermis with weakly cutinized lateral walls. Such a structure possibly provides more elastic properties. The epidermis of fruits susceptible to injury—line No 155/84 (Fig. 5) — was heavily cutinized. The cultivars Atma and Wenus showed intermediate properties.

Analysis of the present results indicates that good mechanical qualities of the fruit are correlated with a flattened shape of epidermal cells and thick hypodermis composed of 4-5 rows of cells. Deep penetration of the cuticle into the hypodermis is also characteristic for resistant fruits. Cotner et al. (1969) report similar characteristics of the shape of epidermal cells in fruits resistant to injury. They indicate that mechanically resistant fruits have a thick hypodermis (3-4 rows of cells) and have observed deep penetration of the cuticle into hypodermal cells. Their results therefore fully coincide with ours. Our results

Table 2
Thickness of epidermal cell walls in ripe tomato fruits
(μm)

Cultivar	Average for 15 fruits
Kecskemeti 886j-2	0.66
Campbell 28	0.88
Atma	2.20
Wenus	2.42
Line No 155/84	4.40

contradict the suggestion of Chu and Thompson (1972b, c) who considered that resistant fruits have only a single-rowed hypodermis.

Some authors (Hankinson and Roa, 1979, Pagalday, 1984) claimed that mechanically resistant fruits possess mesocarp with flattened parenchymatous cells and with small intercellular spaces. Also this observation agrees with ours.

Chebanu (1972) maintains that the thinner the cuticle layer, the deeper its penetration into the pericarp. We have observed the same in the investigated cultivars, but only when the thickness of the cuticle was observed on the lateral walls of the epidermis (Plate 2).

Our four-year studies show that the anatomical structure of the tomato fruit pericarp is characteristic for the given cultivar and is little influenced by year to year changes in environmental conditions. These results support the claim that anatomical examination of the tomato pericarp may be helpful to breeders as an additional method to check the degree of susceptibility of a cultivar to external injury.

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Związek budowy anatomicznej perykarpu owoców pomidora (*Lycopersicon esculentum* Mill.) z właściwościami mechanicznymi

Streszczenie

Badano strukturę anatomiczną perykarpu owoców pięciu odmian pomidorów gruntowych samokończących (*Lycopersicon esculentum* Mill.). Owoce badanych odmian różniły się właściwościami mechanicznymi. Badano odmiany o owocach: twardych i odpornych na zewnętrzne uszkodzenia (Kescskemeti 886j-2, Campbell 28), średniotwardych i średnioodpornych (Atma, Wenus) oraz miękkich i podatnych na uszkodzenia (linia Nr 155/84).

Odmiany, których owoce były twarde i odporne na zewnętrzne uszkodzenia miały warstwę okrywającą owocu (kutykula, epiderma i hypoderma) grubości około 200 μm , a miękkie i podatne tylko około 100 μm . W owocach odpornych na zewnętrzne uszkodzenia kutykula wnika do hypodermy, komórki epidermy są spłaszczone, a hypoderma zbudowana jest z 4-5 warstw komórek. Owoce pomidorów odporne na zewnętrzne uszkodzenia mają boczne ścianki epidermy słabo skutynizowane natomiast podatne — mocno skutynizowane.