SUMMARY

A root growing in soil is exposed to mechanical stress, whose occurrence and nature depend on the compaction of the substrate and the shape and size of its elements. These traits of the substrate affect the growth and morphology of the root. Roots growing in dense media are shorter and have larger diameters than roots growing in loose substrate. Morphological changes affect anatomical features of the root, such as an increase in the cortex thickness, which is sometimes associated with an increase in the number of cell layers or an increase in the radial dimension of the cells of this tissue.

Experiments examining the morphological response of roots to growth conditions generally use a medium of one type but with different packing levels or particle sizes. However, there are no reports on the response of roots of a given species to media with different physical properties. Relatively little is known about the effect of growth conditions on the mechanical properties of roots. Eventually, there is a lack of research verifying a potential relationship between roots' morphology, anatomy and mechanical properties.

The research objects were the roots of two crop species: maize (*Zea may*s L.) and cabbage (*Brassica oleracea* L.). These plants have a fibrous and tap root system, respectively. The aim of the study was to verify the effect of media of different densities and structures and the effect of available growth space on the morphological and anatomical traits of the roots of these plants, as well as to determine the most important mechanical modules and parameters of primary roots of maize.

Three types of growth media were used in the experiment: sandy loam soil, glass beads of different diameters (two sizes for each plant species) and vermiculite, and containers of two different shapes were applied: large cylinders and tight, almost two-dimensional aquariums. Plants were grown in containers filled with the media for 14 (maize) or 21 (cabbage) days under controlled conditions, then extracted from the media and used for analysis. The study involved three separate parts, using different methods.

In the first part, relating to the study on the effects of the medium on the morphological traits of the roots, the root systems were scanned, and the resulting images were analyzed to obtain morphometric data of the primary roots of maize and the main roots of cabbage and the laterals of both. These data were compared between variants of the experiment, separately for each species. The results showed that the most significant effect on the root morphology in

maize and cabbage had the growth medium; slightly less effect came from the interaction between the factors, and the container was of the most negligible significance. Generally, the roots grown in vermiculite were the most outliers regarding morphological traits; they were longest and usually very thin. The roots of the other variants were shorter and thicker. Both in maize and cabbage, the shortest roots came from smaller glass beads. Root length positively correlated with root area and volume, while it negatively correlated with root diameter. In both maize and cabbage, the largest number of lateral roots was observed in plants growing in vermiculite.

The second part concerned the study of the effect of the growth medium on the anatomical traits of the primary root of maize and the main root of cabbage. Using a microtome, cross-sections were obtained in the elongation zone and mature tissue zone of the roots. Histochemical staining using phloroglucinol and Sudan red 7B was used to detect lignin and suberin, respectively. In the roots of both species, the cell arrangement was more regular in the elongation zone than in the mature tissue zone. Maize roots grown in glass beads and vermiculite showed significant damage to the rhizodermal cell and a disrupted cell arrangement in the cortex and vascular cylinder. In these roots, the exodermis and endodermis differentiated closer to the root tip than in the roots from the soil, whose cell arrangement was the most regular. The phi thickenings were detected in the cortex in cabbage roots growing in soil, smaller beads and vermiculite. In roots grown in larger beads and, in some cases, also in vermiculite, there were three, instead of the typical two, protoxylem poles in the vascular cylinder.

In the last part of the study, the mechanical moduli and parameters of the primary roots of maize growing in cylinders were determined using a materials testing machine. The greatest elasticity modulus and strength were found in roots grown in vermiculite, while the lowest values of these properties were found in roots grown in soil. The latter had the highest stiffness. Strength tests of the lower, central and upper root fragments showed that the values of the mechanical moduli and parameters increase along the root axis in the basal direction.

The results of the three parts of the study indicate that the medium in which the root grows significantly affects its morphology, anatomy and mechanical properties. Of the growth media used here, vermiculite - a light and porous medium has the least favourable effect on these characteristics. Roots from this medium are the thinnest, although the longest, their cell arrangement is disturbed, reaching the deepest tissues, and they have the lowest stiffness. A

heavy medium of rigid glass beads also appears unfavourable, as it reduces root growth and causes changes in cell arrangement comparable to those of vermiculite roots. In contrast, the most favourable environment for root growth is soil, a medium with high density and small movable particles. Roots growing in soil have the largest diameters, regular cell arrangement and highest stiffness. The results have also shown that the roots of plants with different types of root systems respond to the conditions of the growth medium in similar ways.