Endo-adaptive mechanisms of mesophytic plants’ functioning as a component of ecosystem resistance

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Abstract. The ecological state deterioration of the biosphere contributes to the formation of structural-functional mechanisms of plants’ adaptation to the synergistic influence of negative factors at different levels of living systems’ organization. A complex algorithm of the plant organism reaction response to any adverse factor includes a wide range of histological-metabolic adaptive mechanisms that provide a nonspecific reaction and are responsible for increasing the plant organism resistance. Aim is the investigation of endo-adaptive specificity of mesophytic plants’ formation as an ecosystem resistance component. Methods are experimental research, quantitative and anatomical analysis, mathematical and statistical processing of the obtained data. The article presents the histological-functional specificity of Portulaca oleracea L. vegetative organs under chloride load and without it in the Ukrainian south conditions. It is proved that the various parameters study of plants’ metabolism and anatomical-morphological reconstruction plays an important role in studying the salt resistance mechanisms, which determine the existence of mesophytic plants under stressful environmental changes. It is shown that adaptability is an equal component of two interdependent processes (the development of damage caused by stressors and the restoring the values of structural-functional parameters), which generally forms an endo-adaptive mechanism of plant functioning and ensures steadiness of ecosystem stability.

1. Introduction

The south of Ukraine forms a zone of risky agriculture, which is characterized by a temperate-continental climate with hot summers, high solar insolation and significant water shortages, and soil salinity causes poverty and specificity of natural flora [1–3]. Salt resistance of plants is an urgent problem of crop production, attracts the attention of many researchers and practitioners of agriculture due to the need to increase yields on saline soils and the development of new lands. Soil salinization causes great damage to agriculture, reducing crop yields [4–7]. The study of the relationship of plants with the environment is of theoretical interest in terms of understanding the mechanism of action of salts on the plant organism and the corresponding reactions of the organism. In addition, under natural conditions, the toxicity of salts depends on a number of other reasons: soil moisture, its mechanical composition, the presence of nutrients [8–12]. However, despite the enormity and complexity of the problem of salt tolerance, its solution largely depends on knowledge of the nature of salt tolerance, knowledge of the adaptability to...
salinization of the soil of various herbaceous and woody plants, and the effectiveness of methods to increase salt tolerance. Thus, the problem of salt resistance is an important aspect of the dynamic evolutionary ecology of plants [13–17]. Therefore, salt resistance should be understood as an ecological and physiological phenomenon, which is formed mainly on the study of its own mechanism of stability and understanding of the active adaptation that characterizes the plant. Mesophytic plants fight overheating and salinization by vertical arrangement of leaves, folding and folding of leaf blades, increasing the intensity of transpiration [8, 18]. More heat–resistant mesophytes are characterized by increased cytoplasmic viscosity and cell juice concentration, increased synthesis of heat–resistant enzyme proteins. Heat–resistant plants are characterized by specific morphological and anatomical features of the structure of individual organs, have a reduced level of metabolic processes, have high viscosity of the cytoplasm, high content of bound water in the cell, etc. In order to derive sustainable cultivated plants, this issue is becoming increasingly important [19–21]. Using this ability, especially at a young age, you can change the nature of the plant and create high–yielding forms, able to withstand various types of salinity, soil and air drought and bring in these conditions a larger harvest, which is very important for humans.

**Aim** is the investigation of endo–adaptive specificity of *Portulaca oleracea* L. mesophytic plants’ formation under chloride loading and without salinization during ontogenesis as a component of ecosystem resistance.

2. Methodology
During the theoretical study of the problem, research and experimental work, general scientific research methods were used: theoretical analysis and generalization of scientific and methodological literature on morphology, anatomy and ecology of plants, periodicals; experimental method, quantitative anatomical analysis, mathematical and statistical processing of the obtained data [8,19]. Determination of the vegetative organs size of experimental plants was carried out according to generally accepted morpho–anatomical methods [4,6], physiological characteristics were studied according to generally accepted physiological methods [19]. The data statistical analysis was performed using Microsoft Excel and Statistica 8.0. The average measurement error does not exceed 5%.

3. Results
The data analysis showed that the *Portulaca oleracea* L. root has the following structure: bark (71.02%), periderm (15.26%), cambium (0.96%), wood (3.13%), xylem bundles of three levels (9.63%): the first – 2.43%, the second – 3.2%, the third – 4.0% (figure 1). At the root of the cortex parenchyma does not perform a water–retaining function. Here, probably, some important substances are synthesized, as well as spare substances accumulate. Here, in the vacuoles of the cells of the parenchyma of the cortex, salts are deposited, which come in excess to the plant. Elements of a phloem are very weakly traced in a parenchyma of bark. Our studies have shown that in saline proportions of *Portulaca oleracea* L. root tissue acquires the following values: bark (71.3%), periderm (14.88%), cambium (0.87%), wood (3.21%), the xylem bundles of three levels (9.74%): the first – 2.5%, the second – 3.23%, the third – 4.01%. It has been proven that in *Portulaca oleracea* L. the tips of the roots are damaged and brown, and this leads to the intensive appearance of lateral roots of the 2nd and 3rd levels. This changes the spatial structure of the root system, which on saline soils is located in the surface layers of the soil. NaCl salts significantly accelerate the lignifications of the inner walls of epidermal cells and cause their thickening. Regardless of the root growth conditions, the rate of woodiness of their cells does not change. This process is a specific protective reaction aimed at creating a barrier that limits the entry of salt ions into the plant.
Figure 1. Histological ratio in the *Portulaca oleracea* L. root: 1 – bark, 2 – periderm, 3 – cambium, 4 – wood, xylem bundles of three levels: 5 – first, 6 – second, 7 – third.

The study of the internal structure of the *Portulaca oleracea* L. stem showed that the epidermis is 0.15% of the stem total thickness. Under the epidermis is a small layer of collenchyma – 2.39%. Behind it is the cortex parenchyma – living, large cells that perform a water-storing function, which accounts for 2.39%. And in general the bark is 7.32%, which is also 3 times less than at the stem top. The bark is followed by meristematic tissue – cambium, which is 0.16% of the total cut. The layer of wood here is represented by sclerenchyma and vascular–fibrous bundle. The sclerenchyma lies in a continuous layer, as it accounts for 11.36% of the total ones. Behind the sclerenchyma are collateral vascular–fibrous bundles located in a circle. They are larger than in the upper part and make up 11.36% of the total cut size, and in total wood occupies 19.13%. The xylem vessels are directly adjacent to the core cells, which ensures the unimpeded transition of the required amount of water and minerals immediately into the bundles, and from there to the desired parts of the plant. The core is represented mainly by round or medium water–storing cells. Round cells of the 3rd level, their size is 5.53% of the total thickness; 2nd level cells – 3.29; 1st level cells are not even observed.

After the NaCl action, the plant *Portulaca oleracea* L. formed a characteristic morphological structure, and this corresponds to the anatomical features: bark – 4.85%, collenchyma – 2.32%, bark parenchyma – 2.32%, cambium – 0.16%, wood – 19.34%, sclerenchyma – 11.37%, VFB – 11.37%, core – 39.51%; cells of the 2nd level – 3.22%, cells of the 3rd level – 5.54% (figure 2) . It is shown that assimilation shoots are sluggish, translucent, pale green; epidermis cells, parenchyma, cortex parenchyma and vascular bundles decreased significantly in size.

Of all the plant organs, the leaf is most closely connected with the environment in the process of intensive metabolism – photosynthesis and transpiration. Therefore, its structure much more strongly reflects the impact of changing environmental conditions. The external morphological diversity of the leaf is accompanied by the same diversity of its anatomical structure. Above and below the leaf is covered with a single layer of epidermis. The epidermis is represented by large, thin–walled cells that are tightly pressed together. The main cells form a cover that protects the cells from drying out, mechanical damage, and infection. The leaf epidermis is 2.58% of the total thickness of the leaf. Compared with the control of the epidermis for salinity decreased in size and amounted to 1.5%.

Using morpho–anatomical methods Zakharevich S.F. [6] in the study of the main cells of the
Figure 2. The tissues ratio of the *Portulaca oleracea* L. stem: 1 – bark, 2 – collenchyma, 3 – the bark parenchyma, 4 – cambium, 5 – wood, 6 – sclerenchyma, 7 – VFB, 8 – core.

leaf integumentary tissue, we identified two types of cells that differ in size, projection: – 240 pcs., cell size along the long axis – 720 microns; \( S = 4800 \, \mu m^2 \); type II – projection of cells 5–6 angular, angles – pointed and obtuse, the number of cells per 1 \( mm^2 \) – 150 pcs., cell size along the long axis – 360 \( \mu m \); \( S = 1200 \, \mu m^2 \). The type of respiratory system is anomocytic.

Under the NaCl action there are the following anomalies of the respiratory complexes: type I – two stomata are in one polygonal cell, the contours of the cell – rectilinear, sharp, obtuse angles; type II – the stomata are surrounded by two cells, on the one hand a hexagonal cell, on the other a 5–cornered cell, cells with rectangular faces, with pointed and obtuse angles; type III – stomata are accompanied by two cells, one of which is much larger than the other; type IV – the stomata are surrounded by a pair of epidermal cells, whose common walls are at right angles to the closing cells (diacytic type of the respiratory tract). According to some authors [3, 5–7, 9–12, 14–17, 20] abnormal respiratory complexes occur under the influence of stress, in this case under the NaCl action.

On average, the short axis of the respiratory cell is 240 \( \mu m \), the long – 300 \( \mu m \). The stomata number is 140 pieces/\( mm^2 \).

After the epidermis is the mesophile, which is differentiated into photosynthetic and aquifer parenchyma. The photosynthetic parenchyma is 54,22 % of the total thickness. The aquifer parenchyma is represented by large water–storing cells and is 32,27 % of the total leaf thickness.

As a result of the constant shortage of water, the plant, receiving excess water, tries to keep it on a rainy day in the maximum amount and wherever possible. In this case, in the *Portulaca oleracea* L. leaf such a storage tissue becomes the aquifer parenchyma. The aquifer parenchyma is surrounded by lining cells. In the center of the leaf is a vascular–fibrous bundle, and is 9,89%. It consists of the beam xylem zone, located farther from the stem, and the beam phloem zone (closer to the stem).

It was determined that the leaf under the NaCl action became sluggish, pale green, inanimate, acquired a characteristic morphological structure, and this corresponds to the anatomical features: cuticle (0,94%), epidermis (2,44%), photosynthetic parenchyma (54,39%), aquifer spongy parenchyma (32,45%), the leading bundle (9,78%) decreased significantly in size, there were multifaceted friends of rectangular shape due to stress.

Analyzing the data on the weight of one seed and the number of seeds in plants, a pattern is
observed (table 1). In *Portulaca oleracea* L. on saline soil the seeds are small, and in *Portulaca oleracea* L. in control more. It was found that 75% of seeds germinate in the control of *Portulaca oleracea* L. plants, and 58% in saline plants.

Adaptation of *Portulaca oleracea* L. can be assessed according to the variability level of physiological–biochemical parameters and anatomical–morphological adapted changes at different levels of the organization during ontogenesis, which characterize the “reliability” of a particular genotype. In this case, the plant productivity, as the final integrated indicator, finally shows the influence degree of the active factor on the plant, and the analysis of the productivity components, to some extent, allows determining the main directions and magnitudes of this impact.

**Table 1.** *Portulaca oleracea* L. productivity (SP – Seed productivity; CSP – Coefficient of seed productivity).

| Experiment option | Seed diameter, µm | Seed weight, mg 1000 pcs | Mass one seed, mg | SP Potential | SP Real | CSP |
|-------------------|-------------------|--------------------------|------------------|--------------|--------|-----|
| Salinity          | 875,6±1,3         | 360±0,9                  | 0,36±0,9         | 500±100      | 50±0,7 | 0,58±0,5 |
| Control           | 908±1,4           | 390±1,2                  | 0,39±1,1         | 250±40       | 120±1,2 | 0,75±0,7 |

Full realization of the *Portulaca oleracea* L. potential productivity is possible only in the presence of favorable conditions for its vital activity. Features of individual plant development are determined by genotype, response rate and level of its implementation in the phenotype, which largely depends on environmental conditions, including water supply during the growing season.

Accordingly, finding out as many reasons for reduced productivity, identifying the main directions and depth of stress, in this case – salinity, are a necessary prerequisite for the development of scientifically sound technologies for growing plants for rational and efficient use of saline and plant resources in specific areas.

**4. Conclusion**

The learning of a complex of histological–functional changes, coordinated by self-regulation of the plant organism, in particular *Portulaca oleracea* L., is important for studying the mechanisms of salt resistance of mesophytic plants in southern Ukraine. Than higher the level of biological organization (cell, organism, population, biogeocenosis) that greater the number of mechanisms involved in the adaptation of plant organisms to stressful environmental conditions. Histological and functional characteristics of *Portulaca oleracea* L. allow a clearer understanding of the plant adaptation mechanism to environmental conditions, which forms a correct conception of endo–adaptive mechanisms of mesophytic plants’ functioning as part of ecosystem resilience.

Generalized structural analysis of the obtained data showed that the *Portulaca oleracea* L. root has the following structure: bark (71,02%), periderm (15,26%), cambium (0,96%), wood (3,13%), bundles xylems of three orders (9,63 %): the first – 2,43%, the second – 3,2%, the third – 4,0%. It is proved that at salinity the root tissues ratio of this plant acquires the following values: bark (71,3%), periderm (14,88%), cambium (0,87%), wood (3,21%), xylem bundles of three orders (9,74 %): the first – 2,5%, the second – 3,23%, the third – 4,01%.

It was found that the internal structure of the *Portulaca oleracea* L. stem is represented by the following components: epidermis of the bark (0,15%), collenchyma (2,39%), the bark
parenchyma (2.39%), cambium (0.16%), wood (19.13%), sclerenchyma (11.36%), VFB (11.36%), core (8.82%). After the NaCl action this plant formed a characteristic morphological structure, which corresponds to the anatomical features: bark — 4.85%, collenchyma — 2.32%, the bark parenchyma — 2.32%, cambium — 0.16%, wood — 19.34%, sclerenchyma — 11.37%, VFB — 11.37%, core — 39.51%.

It is shown that the epidermis forms 2.58% of the total leaf thickness of Portulaca oleracea L. compared with the control of the epidermis in salinity decreased in size and amounted to 1.5%, and also had anomalies of the stomatal complexes. The leaf under the NaCl action became sluggish, pale green, lifeless, acquired a characteristic morphological structure, and this corresponds to the anatomical features: cuticle (0.94%), epidermis (2.44%), photosynthetic parenchyma (54.39%), aquifer spongy parenchyma (32.45%), the leading bundle (9.78%) decreased significantly in size, there were multifaceted friends of rectangular shape due to stress.

These researches show that in Portulaca oleracea L. on saline soil the seeds are small, and in control more ones; in control 75% of seeds germinate, and on saline – 58%.

Thus, adaptability is an equal component of two interdependent processes – the development of damage caused by stressors, and the restoration of structural–functional parameters, which generally forms an endoadaptive mechanism of plant functioning and ensures the ecosystem stability.

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