GRAVISENSITIVITY OF PLANT CELLS: STATUS AND PROSPECTS

Kordyum Elizabeth L.

Institute of Botany, National Academy of Sciences of Ukraine,
2, Tereschenkovskaya str. 01004 Kiev, Ukraine, Email: cell@svitonline.com

ABSTRACT

A discovery of gravisensitivity of plant cells specialized and not specialized to gravity perception stimulated the intensive research of cell biology in altered gravity. In order to better understanding of the possible mechanisms of this phenomenon, it is proposed to distinguish between cell gravisensing and graviperception. It is assumed that proliferative and actively metabolizing cells are the most sensitive to the influence of altered gravity. Grounded on the hypothesis of gravitational decompensation, the consequences of events occurring in plant cells under the microgravity action are discussed. Prospects of future research in this field are proposed.

INTRODUCTION

One of fundamental achievements of modem biology is a discovery of gravisensitivity of plant cells based on the data of experimental investigations in the field of space and gravitational biology. The experiments with plants in vivo and in vitro, which were performed in the conditions of real microgravity on board the biosatellites "Kosmos", orbital stations "Salyut" and "Mir", and space Shuttles allowed to elucidate the main regularities of biological effects of microgravity and, thus, firstly to value a role of gravity in plant vital activity at the cellular and molecular levels, and to obtain new knowledge on mechanisms of both graviperception and plant growth tropic movements, which provide space orientation of their organs in the gravitational field [1-4]. In connection with intensive research of biology of plant cells in microgravity, which are specialized and not specialized to gravity perception, it seems better to distinguish between cell graviperception and cell gravisensing.

GRAVIPERCEPTION

It is related to actively using a gravitational stimulus by cells, in first turn, those specialized to gravity perception, for realization of plant normal space orientation, growth, and vital activity (gravitropism, gravitaxis). The structure of graviperceptive cells is diverse, but gravisusceptors are known. These are statoliths of different types that change their position in the direction of the gravity vector and thus initiate the next steps of the gravitational response. Graviperceptive cells are differentiated in microgravity, e.g. root cap statocytes, but do not function in the absence of a gravitational vector. Amyloplasts do not sedimented in the distal part of a statocyte that confirms their statolithic function [4-6]. Unlike the multicellular graviperceptive organs, in tip-growing plant cells, e.g. *Chara* rhizoids, the processes of graviperception and growth gravitropic reaction are the function of the same cell. In *Chara* rhizoids, the statoliths - compartments filled with crystallites of barium sulfate - also change their position under microgravity [7]. Flight experiments, in which the rhizoids were treated immediatelly before the flight with cytochalasin D, fully supported the hypothesis on the balance between the gravitational force and the basipetally acting force generated in a dynamic interaction of statoliths with actin microfilaments [8].

GRAVISENSING

It is related to cell structure and metabolism stability in the gravitational field and their changes in microgravity. Therefore, the concepts on positional homeostasis [9], static stimulation [10], passive gravistimulation [11], .and restrained gravisensing [12] are more effective for understanding of some aspects of cell gravisensing. A discovery of cell gravisensing has been made on the basis of the metabolism and ultrastructure changes occurring in cells, not specialized to gravity perception, in microgravity. In addition, there are data on changes in the intracellular concentration and/or distribution of Ca^{2+} ions in altered gravity, that assumes the Ca^{2+} messenger role in biochemical regulation of cell processes in these conditions. Grounded on these experimental results, it is assumed that proliferating and actively metabolizing cells are the most sensitive to the influence of altered gravity. Simultaneously, this assumtion propounds the next questions: 1) what primary events underlie metabolism changes in microgravity, 2) what second messengers take part in transfer of the primary signals of microgravity, 3) whether gene expression changes in microgravity, 4) what peculiarities of cell metabolism regulation may be in microgravity, 5) why carbohydrate and lipid metabolism is the most sensitive to the influence of microgravity, 6) whether the parameters of a cell cycle and proliferation activity change in microgravity, and 7) how the metabolism changes in microgravity are integrated in physiological responses in the cells of different types directly connected with realization of their functions. Trying to answer these questions, a hypothesis of gravitational decompensation was proposed [3].

Proceedings of "Life in Space for Life on Earth", 8th European Symposium on Life Sciences Research in Space, 23rd Annual International Gravitational Physiology Meeting, Karolinska Institutet, Stockholm, Sweden, 2 – 7 June 2002 (ESA SP-501, September 2002)

According to this hypothesis, under the conditions of reduction or the absence of hydrostatic pressure, a change in the surface tension of the cytoplasmic membrane can play an inductor role in the rearrangements of its physical-chemical properties. The effect of such an inductor increases owing to its heterogeneity over the length of the cytoplasmic membrane. This assumption is based on the following: 1) hydrostatic pressure and surface tension may interfere with biological processes by changing membrane fluidity [13], recently it has been found the alterations in the indices of cytoplasmic membrane fluidity in microgravity, 2) an enhanced lipid peroxidation intensity in microgravity and changes in the ratio of saturated and unsaturated fatty acids, 3) changes in Ca^{2+}-ATPase activity, 4) an appearance of complex folds of the cytoplasmic membrane and Ca^{2+} membrane-bound sites in microgravity, and 5) the presence of events termed "piezoeffects" that can complicate the tension state of the membrane surface. The rearrangements in physical-chemical properties of the cytoplasmic membrane underlie the changes in its permeability, receptors' functions, membrane-bound enzyme activity etc., that, in its turn, leads to the next metabolism changes resulting in physiological responses of cells and organisms on the action of microgravity, as shown:

Gravitational decompensation
↓
Change of cytoplasmic membrane surface tension
↓
Change of physical-chemical properties of the cytoplasmic membrane resulting in the changes in its functioning
↓
Metabolism rearrangements
↓
Physiological responses

In light of these ideas, it has been possible to explain the facts of cell metabolism and ultrastructure rearrangements when morphogenesis and cell differentiation are normal in microgravity.

PROSPECTS

An analysis of current state of the problem on plant cell gravisensitivity allows to consider some approaches to the solution of this problem. The main focus in future investigations of plant cells in microgravity should be on events 1) occurring at the membrane level (physical-chemical properties of cell membranes, especially the cytoplasmic membrane and the tonoplast as well as ion and water transport and 2) providing the transduction of primary microgravity effects in the integrated intracellular processes, the modifications of which are demonstrated using electron microscopic, physiological, biochemical, molecular-biological, and other methods. That is why the most significant questions are those that involve the functioning of second messenger systems in plant cells, gene expression and its regulation at different levels, as well as the state of the phytohormone complex and phytohormonal regulation. As before, investigations of topography and structural-functional organization of cell organelles, especially vacuoles, mitochondria, and endoplasmic reticulum, which are a depot of calcium ions, as well as the cytoskeleton should pay attention to the structural basis of metabolic processes and how cell functions are carried out. Undoubtedly, the photosynthetic apparatus and its functioning is one of the most important. In addition, experimental testing of hypotheses on the mechanisms of graviperception should be perormed. The results of such fundamental studies are necessary for understanding how gravity works at the cellular and molecular levels., as well as the basis for developing space cell biotechnology and space planting technologies in CELSS.

REFERENCES

1. Halstead T.W. & Dutcher F.R., Plants in space, *ANNU REV. PLANT PHYSIOL.*, Vol. 38, 317-345, 1987.
2. Claasen D.E.& Spooner B.S., Impact of altered gravity on aspects of cell biology, *INT. REV. CYTOL.*, Vol. 156, 301-373, 1994.
3. Kordyum E.L., Biology of plant cells in microgravity and under clinostating, *INT. REV. CYTOL.*, Vol. 171, 1-78, 1997.
4. Sack F.D., Plastids and gravitropic sensing, *PLANTA*, Vol. 203, 63-68, 1997.
5. Kiss J.Z. & al. Reduced gravitropism in hypocotyls of starch-deficient mutants of Arabidopsis, *PLANT CELL PHYSIOL.*, Vol. 38, 518-525, 1997.
6. Kordyum E. & Guikema J., An active role of the amyloplasts and nuclei of root statocytes in graviperception, *ADV. SPACE RES.*, Vol. 27, 951-956, 2001.
7. Volkmann D. & al. Oriented movement of statoliths studied in a reduced gravitational field during parabolic flights of rockets, *PLANTA*, Vol. 185, 153-161, 1991.
8. Buchen & al. Statoliths pull on microfilaments. Experiments under microgravity. *PROTOPLASMA*, Vol. 172, 38-42, 1993.
9. Nace G.W., Gravity and positional homeostasis of the cell, *ADV. SPACE RES.*, Vol. 3, 159-168, 1983.
10. Sievers A. & al. Role of the cytoskeleton in gravity perception. In: *The Cytoskeletal Basis of Plant Growth and Form*, ed. C.W. Lloyd, Academic Press, London-Toronto, 169-182, 1991.
11. Barlow P.W., A conceptual framework for investigating plant growth movements, with special reference to root gravitropism, utilizing a microgravity environment, *MICROGRAV. QUART.*, Vol. 2, 77-87, 1992.
12. Baluska F.& Hasenstein K.H., Root cytoskeleton: its role in perception of and response to gravity, PLANTA. Vol. 203, 69-78, 1997.
13. Shinitzky M., *Physiology of Membrane Fluidity*, CRC Press, Boca Raton, FL, 1984.