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EFFECT OF THE PHOTOPERIOD ON THE PLASMA MEMBRANE ATP-DEPENDENT H⁺-PUMPING ACTIVITY OF SPINACH PETIOLES

BY

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ABSTRACT

Effect of the photoperiod on the plasma membrane ATP-dependent H⁺-pumping activity of spinach petioles. - The plasma membrane from spinach (*Spinacia oleracea*, cv.Nobel) petioles was purified by phase partitioning and the use of enzyme markers showed that this fraction was highly enriched in plasma membrane vesicles. This fraction was almost devoid of phosphohydrolase activities originating from endomembranes (tonoplastes, mitochondria, non specific phosphatases and golgi apparatus). The ATP-dependent H⁺ pumping activity in this fraction was Mg²⁺ and K⁺ dependent and was not stimulated by valinomycin. It was insensitive to nitrate (tonoplaste ATPase inhibitor) but sensitive to vanadate (plasma membrane ATPase inhibitor). This activity was specific for ATP and had a pH optimum around 6.5. The kinetic constants (K_m_{app} and V_{max} for ATP) of the H⁺ pumping activity of the purified plasma membrane were determined from plants grown in short days (vegetatives) and from similar plants induced by 24 h of continuous light. Whereas K_m_{app} have not been changed after light induction, values of V_{max} and the activity in the presence of 0.5 mB ATP have been increased suggesting a regulation of the enzyme after light induction.

Key-words: H⁺-ATPase, Plasma membrane, *Spinacia oleracea*.

Abbreviations: ADP, Adenosine diphosphate; ATP, Adenosine triphosphate; BSA, bovine serum albumin; BTP, bis-tris-propane (1,3-bis (tris (hydroxymethyl) methylamino) propane); DTT, dithiothreitol; GTP, Guanosine triphosphate; IDP, inosine diphosphate; Mes, 4-morpholinoethane sulfonic acid; PNPP, p-nitrophenylphosphate; PMSF, phenylmethylsulfonylfluoride; PP_i, Pyrophosphate; Tris, Tris (hydroxy methyl)-aminomethane; UDPG, uridine diphosphoglucose.

INTRODUCTION

The plasma membrane of cells plays a crucial role in the perception, transduction and transport of environmental signals within the cell leading to a particular response. One of the important enzymes which seems to control growth, development, nutrient transport and stomata movements is the H⁺-pump of the plasma membrane (SERRANO, 1989). Reflecting the physiological importance of this activity, it is to be expected that the enzyme is subject to strict regulation *in vivo* by plant growth factors such as plant hormones, growth-modifying pathogens and light (ASSMANN *et al.*, 1985; BIDWAI *et al.*,

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1987; CLELAND, 1987). This enzyme belongs to the P-type family of cation-translocating enzymes characterized by formation of phosphorylated intermediate, inhibition by vanadate and structural similarity in several conserved domains (SERRANO, 1989). It generates an electric potential and pH gradient (H^+ motive force) that drive solute movements cross the plasma membrane. In plants (e.g. tobacco, tomato, *Arabidopsis thaliana*) the plasma membrane H^+ -ATPase is encoded by a multigene family, members of which are differentially regulated from one tissu to another within the plant and in a same tissu in response to different developmental or environmental conditions (PARDO & SERRANO, 1989; HARPER *et al.*, 1990; ROLDAN *et al.*, 1991; HASE, 1993; EWING & BENNETT, 1994).

Different studies underwent on spinach demonstrated that the plants could be induced to flowering by different chemical and physical ways (AUDERSET & GREPPIN, 1976). In this paper, we report the purification of the plasma membrane from spinach petioles (*Spinacia oleracea*, cv.Nobel). The highly purified plasma membrane fraction suitable for biochemical studies was characterized by enzyme markers and the activity of the H^+ -ATPase was first characterized and tested after flowering induction of the plants.

MATERIAL AND METHODS

Plant Material

Spinach (*Spinacia oleracea*, cv.Nobel) plants at the végétative stage were grown in a phytotron for 4 weeks under non inductive short days (SD) of 8 h (8:00 am to 4:00 pm; $400 \mu\text{mol.m}^{-2}.\text{s}^{-1}$) and 16 h dark (4:00 pm to 8:00 am). The light was provided by white fluorescent tubes (40 W, 244332 Sylvania USA). The temperature was set at $20 \pm 1^\circ\text{C}$ and the relative humidity at $80 \pm 5\%$ during the light period and $60 \pm 5\%$ during the darkness respectively. Floral induction was initiated by continuous light treatment (24 h) of plants grown in SD for 4 weeks (AUDERSET & GREPPIN, 1976).

Preparation of microsomal vesicles

Crude microsomal vesicles were prepared as described by DE MICHAELIS & SPANSWICK (1986). Petioles (12 g) were harvested and homogenized at 4°C in a medium (4 ml per g fresh weight) containing 250 mM sucrose, 2 mM EGTA, 2 mM MgSO_4 , 2mM Na_2ATP , 10% (v/v) glycerol, 1 mM PMSF, 2mM DTT, 0.5% (w/v) BSA, 25 mM BTP-MES adjusted to pH 7.6. The homogenate was filtered and centrifuged at $6,000 \times g$ (7,000 rpm, Sorvall, SS-34 rotor) for 10 min at 4°C . The resulting supernatant was filtered through one layer of Miracloth (475855 Calbiochem) and centrifuged at $30,000 \times g$ for 30 min at 4°C . The pellet (crude microsomes) was resuspended in phosphate buffer (KH_2PO_4 : Na_2HPO_4 5mM pH 7.8) and subjected to plasmalemma purification by partitioning in an aqueous polymer two-phase system (12 g system) as described by KJELLBOM & LARSSON (1984). The upper phase was washed one time in a fresh lower phase and the resultant upper phase U_2 was diluted three times in a resuspension medium containing 250 mM sucrose, 10% glycerol, 1 mM DDT, 0.2% BsA, 2.5 mM

BTP-MES pH 7. The plasma membrane vesicles were recovered by centrifugation at 30,000 x g for 30 min at 4°C and resuspended in the same medium. The plasma membrane vesicles were stored at - 80°C until used.

Proton pumping activity

The initial rate of acridine orange absorbance quenching was utilized to measure the plasmalemma proton translocation activity as described by BENNETT & SPANSWICK (1983). This activity was expressed in arbitrary unit (AU) min⁻¹ mg⁻¹ protein. Absorbance was measured with a Perkin-Elmer 320 spectrophotometer at the wavelength of 495 nm. Thawed membrane vesicles (about 20 µg proteins) were incubated at room temperature in 1 ml of 25 mM BTP-Mes pH 6.5, 20 µM acridine orange, 0.25 µM valinomycin, 50 mM KBr and 10 mM MgSO₄. The reaction was started by addition of 1.5 mM Na₂ ATP.

ATPase activity

The plasmalemma ATPase activity was measured at 37°C during 30 min in the presence of 50 mM KCl, 5mM MgSO₄, BTP-Mes 25 mM pH 6.5. The reaction was started by addition of 1.5 mM Na₂ ATP. The membrane vesicles were pelleted at 12,000 rpm (microfuge Sorvall) for 10 min at 4°C and the inorganic phosphate released by ATP hydrolysis was determined by adding 0.2 ml of the resultant supernatant to 0.5 ml of 0.24% (w/v) ammoniummolybdate (in 0.5 M H₂SO₄), 0.96% (w/v) ascorbic acid and 0.8% (w/v) trichloroacetic acid. After incubation at 36°C for 10 min the absorbance at 660 nm was measured.

Other assays

Glucan synthase II was determined after KAUSS & JEBLICH (1985). UDPG sterol-glycosyl transferase was determined after CHANSON *et al.* (1984). NADH dependent cytochrome C reductase was determined after PALMGREN *et al.* (1990). Cytochrome C oxidase was determined after HODGES & LEONARD (1972).

Protein determination

Membrane aliquot (30 µl) was diluted in 1 ml of cold water and centrifuged at 96,100 x g (Beckman, T-50 rotor) for 30 min at 5°C. The pellet was resuspended in cold water (160 µl), and protein was determined using Bio-Rad solution. 50 µl of protein suspension were diluted in 750 µl of water and 200 µl of Bio-Rad solution were added. The resulting solution was mixed and incubated at room temperature for at least 5 min. The OD at 595 nm was measured and proteins were quantified using BSA as standard.

Reproducibility of the data

Each measurement was repeated three times and standard deviation (SD) calculated. For determination of kinetic constants ($K_{m_{app}}$ and V_{max}) and the activity of the H⁺-pumping in the presence of 0.5 mM ATP, extraction and purification of the plasma membrane vesicles was repeated two or three times (see captions of figures).

RESULTS AND DISCUSSION

Plasma membrane vesicles prepared by aqueous phase partitioning were characterized by plasma membrane markers (glucan Synthase II, UDPG sterolglycosyltransferase, proton pumping ATP-dependent) and a possible contamination by endomembranes determined by other markers (NADH-cytochrome C reductase for endoplasmic reticulum, NADH-cytochrome C oxidase for mitochondria). As shown in table 1, the plasma membrane markers were more present in the U₂ fraction than in the endomembranes fraction (lower phase L). However, the NADH-cytochrome C reductase activity was more present in the L fraction than in the U₂ fraction, and the cytochrome C oxidase activity was absent in the U₂ fraction. The IDPase and the pyrophosphatase activities were also absent in this fraction (Tab. 2, Tab. 4), showing that the U₂ fraction is highly plasma membrane enriched.

The H⁺-pumping activity of the purified plasma membrane showed a pH optimum around 6.5 (data not shown), similar to that described for other plant species (DE MICHELIS & SPANSWICK, 1986; BELLAMINE *et al.*, 1994; OLIVARI *et al.*, 1993), and requires ATP as source of energy than other phosphorylated substrats tested. No activity was measured in the presence of GTP, ADPO, PNPP, IDP or PPI (Tab. 2). This activity was Mg²⁺ and K⁺ dependent, and was not stimulated by valinomycin (Tab. 3). It was insensitive to 50 mM KNO₃ (vacuolar ATPase inhibitor) and about 50% inhibited by only 20 µM vanadate (plasma membrane ATPase inhibitor) (Tab. 3). The ATP phosphohydrolase Mg-dependent activity of the purified plasma membrane was almost unsensitive to nitrate, Na-molybdate (non specific phosphatase inhibitor) and azide (mitochondrial ATPase inhibitor), and showed that the purified plasma membrane fraction was almost devoid of phosphohydrolase activities originating from endomembranes as assessed by the effects of nitrate (tonoplast), azide (mitochondria), sodium molybdate and p-nitrophenylphosphate (non-specific phosphatases) or IDP (golgi apparatus) (Tab. 4). These results showed that the ATP hydrolysis and the proton transport into the purified vesicles were mostly due to the plasma membrane ATPase activity.

Kinetic constants (K_{m_{app}} and V_{max} for ATP) of the H⁺ pumping activity were determined from plants grown in short days and from similar plants induced by 24 h of continuous light (Tab. 5). Whereas K_{m_{app}} have not been changed after light induction, V_{max} and the activity in the presence of 0.5 mM ATP have been increased (Fig. 1) suggesting a regulation of the enzyme after light induction of spinach petioles. An enhanced synthesis of the polypeptide or of more active isozyme during plant development may result in the increase of the ATPase activity (ROLDAN *et al.*, 1991; HASE, 1993), but other mechanisms of regulation (e.g. phosphorylation, release of C-terminal domain) may be taken into account (PALMGREN, 1991).

RÉSUMÉ

La membrane plasmique des petioles d'épinard (*Spinacia oleracea*, cv. Nobel) a été purifiée par partition de phase, et l'utilisation des enzymes marqueurs a montré que cette fraction est hautement enrichie de vésicules de la membrane plasmique. Cette

fraction est presque dépourvue des activités phosphohydrolases originaires des endomembranes (tonoplastes, mitochondries, phosphatases non spécifiques et appareil de golgi). L'activité H⁺ ATPase dans cette fraction est Mg²⁺ et K⁺ dépendante, et n'est pas stimulée par la valinomycine. Elle est insensible au nitrate (inhibiteur de l'ATPase du tonoplaste) mais sensible au vanadate (inhibiteur de l'ATPase du plasmalemme). Cette activité est spécifique pour l'ATP et possède un pH optimum de 6.5 environ. Les constantes cinétiques ($K_{m_{app}}$ et V_{max} pour l'ATP) de l'activité enzymatique ont été déterminées chez des plantes cultivées en jours courts (végétatives) et des plantes induites par 24 h de lumière continue. Alors que $K_{m_{app}}$ n'a pas changé après induction, les valeurs de V_{max} et de l'activité en présence de 0.5 mM ATP ont augmenté, ce qui suggère une régulation de l'enzyme après induction lumineuse.

TABLE 1

Characterization of plasma membrane purified by two phase partitioning. Enzyme markers of membranes present in upper phase (U₂) and lower phase (L) after two-phase partitioning of a crude microsomes preparation from spinach petioles. U₂ phase represents the purified plasma membrane fraction. L phase represents the endomembranes fraction. The values are the specific activities \pm SD. The values between parenthesis represent the enrichment relative to the specific activities of the crude microsomal fraction.

| Specific activity of enzyme markers | Crude microsomes | U ₂ | L |
|---|--------------------------|----------------------------|-----------------------------|
| Glucane synthase II (Dpm min ⁻¹ μ g ⁻¹ prot.) | 53.34 \pm 3.04 (1) | 83.42 \pm 3.85 (1.56) | 59.98 \pm 4.23 (1.12) |
| UDPG-sterol transferase (Dpm min ⁻¹ μ g ⁻¹ prot.) | 3.03 \pm 0.13 (1) | 7.74 \pm 0.55 (2.55) | 1.61 (0.53) |
| NADH dep-cyt.C reductase (nmol min ⁻¹ mg ⁻¹ prot.) | 152.3 \pm 0.004 (1) | 82.7 \pm 0.01 (0.54) | 135.2 \pm 0.004 (0.89) |
| Cyt.C oxidase (nmol min ⁻¹ mg ⁻¹ prot.) | 83.3 \pm 0.01 (1) | 0.00 \pm 0.00 (0) | 136.5 \pm 0.003 (1.64) |

TABLE 2

Effect of some phosphorylated substrats on H⁺-pumping activity of the purified plasma membrane. The reaction was started by addition of 1.5 mM of the substrat, and the activities were expressed in AU min⁻¹ mg⁻¹ protein \pm SD. All the substrats were sodium salt and the reaction medium contained 10 mM MgSO₄.

| Substrate | Initial rate of substrat-dependent quenching of acridine orange absorbance (AU min ⁻¹ mg ⁻¹ protein) |
|-----------|---|
| ATP | 22.8 \pm 1.54 |
| GTP | 00 |
| ADP | 00 |
| PNPP | 00 |
| IDP | 00 |
| PPi | 00 |

TABLE 3

H⁺-pumping activity of the purified plasma membrane from spinach petioles. The activity was tested for the effect of magnesium, valinomycin, potassium, nitrate (in this case the KCl was omitted) and vanadate. The results were expressed in specific activities (AU min⁻¹ mg⁻¹ protein) ± SD and values between brackets represent the percentage of the activities to control. The reaction was started by addition of 1.5 mM ATP sodium salt.

| Incubation medium | Specific activity of H ⁺ pumping (AU min ⁻¹ mg ⁻¹ protein) |
|---------------------------------|--|
| Control | 41.96 ± 2.70 (100) |
| Incubation medium without: | |
| - Mg ²⁺ | 00 |
| - Valinomycin | 41.56 ± 4.02 (99) |
| - KBr | 00 |
| Incubation medium with: | |
| KNO ₃ (50 mM) | 42.11 ± 2.97 (100) |
| Na ₃ VO ₄ | |
| 20 µM | 21.69 ± 1.38 (52) |
| 100 µM | 00 |
| 200 µM | 00 |

TABLE 4

ATP hydrolysis activity of the purified plasma membrane from spinach petioles. The activity was assayed in the presence of 50 mM KCl and 5 mM MgSO₄ (control) or with the modifications indicated in the table. When the effect of KNO₃ was tested, the KCl was omitted. The reaction was started by addition of 1.5 mM ATP, PNPP or IDP. All the substrats were sodium salt. The results were expressed in specific activity (µmol P_i min⁻¹ mg⁻¹ protein) ± SD. Values between brackets represent the percent of the specific activity to control.

| Treatment | ATP hydrolase activity ± SD (µmol P _i min ⁻¹ mg ⁻¹ protein) |
|----------------------------|---|
| Control | 0.448 ± 0.009 (100) |
| - Mg ²⁺ | 0.046 ± 0.004 (10) |
| + KNO ₃ (50 mM) | 0.423 ± 0.011 (94) |
| + Sodium molybdate (1 mM) | 0.550 ± 0.01 (105) |
| + NaN ₃ (5 mM) | 0.477 ± 0.008 (106) |
| PNPP (1.5 mM) | 0.045 ± 0.003 (9) |
| IDP (1.5 mM) | 0.070 ± 0.014 (16) |

TABLE 5

Kinetic constants of the H⁺-pumping activity of the purified plasma membrane from spinach petioles. Values of apparent Michaelis-Menten constant ($K_{m_{app}}$), maximal activity (V_{max}) of the plasma membrane ATP dependent H⁺-pumping activity from vegetative plants and plants induced by 24 h of continuous light. $K_{m_{app}}$ is expressed in mM ATP and V_{max} was expressed in AU min⁻¹ mg⁻¹ protein.

| Treatment | Vegetative | Induced |
|------------------|------------|---------|
| <i>Exp. N° 1</i> | | |
| $K_{m_{app}}$ | 0.531 | 0.660 |
| V_{max} | 41.62 | 69.91 |
| <i>Exp. N° 2</i> | | |
| $K_{m_{app}}$ | 0.329 | 0.350 |
| V_{max} | 33.80 | 69.82 |

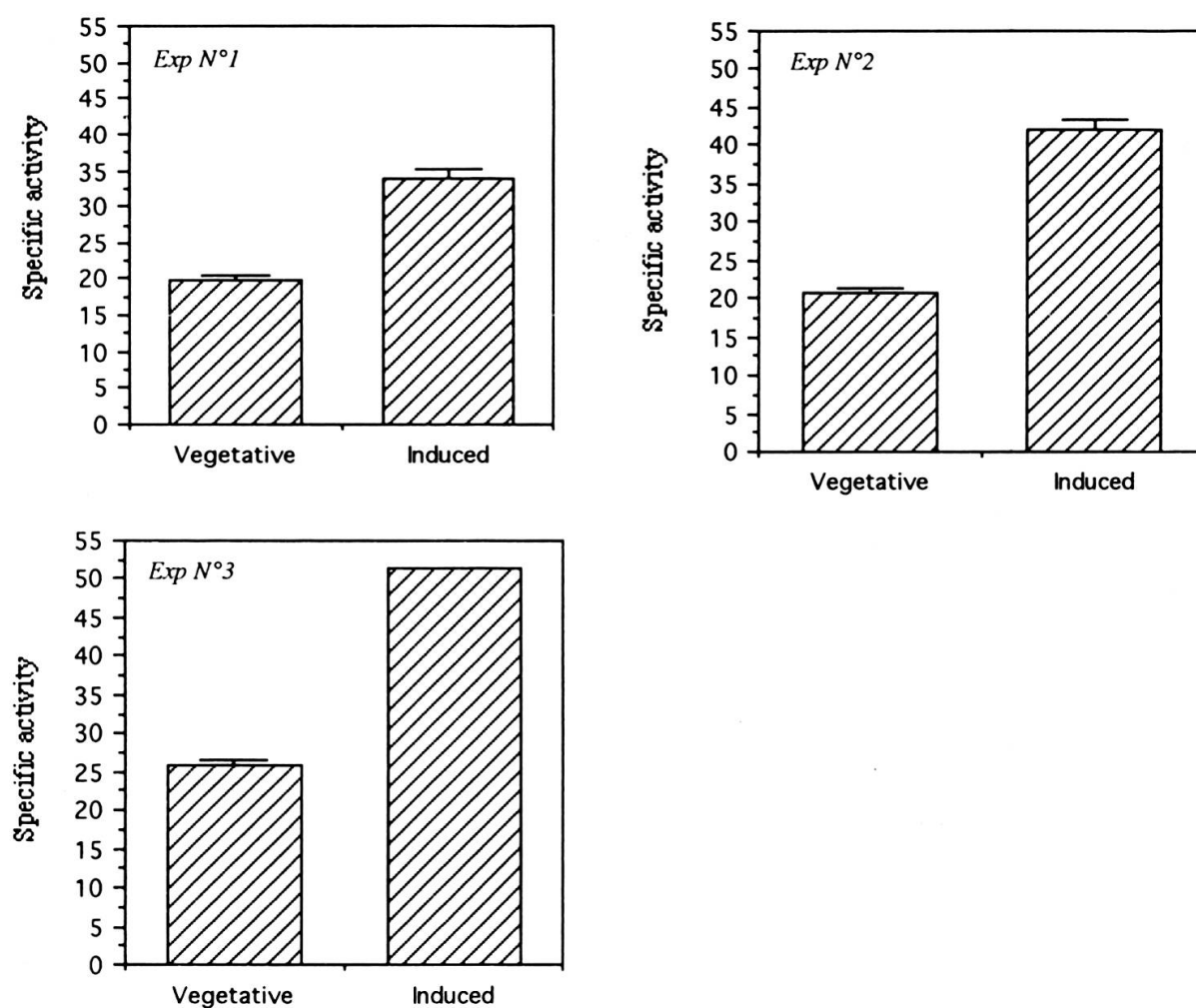


FIG. 1.

Activities in the presence of 0.5 mM ATP of the plasma membrane ATP dependent H⁺-pumping from vegetative plants and plants induced by 24 h of continuous light. They were expressed in AU min⁻¹ mg⁻¹ protein \pm SD. The experiments were repeated three times (Exp N° 1, N° 2, N° 3) with a novel preparation of the plasma membrane.

REFERENCES

- ASSMANN, S.M., L. SIMONCINI & J.I. SCHROEDER. 1985. Blue light activates electrogenic ion pumping in guard cell protoplasts in *Vicia faba*. *Nature*, 318: 285-287.
- AUDERSET, G. & H. GREPPIN. 1976. Etude de l'apex caulinaire de l'épinard avant et après l'induction florale. *Saussurea*, 7: 73-103.
- BELLAMINE, J., C. PENEL & H. GREPPIN. 1994. Effect of photoperiod and gibberellic acid on the plasma membrane H⁺ ATPase activity of spinach leaves. *Biol. Plant.*, 36: 565-573.
- BENNETT, A.B. & R.M. SPANSWICK. 1983. Optical measurements of Δ pH and $\Delta\Psi$ in corn root membrane vesicles: kinetic analysis of Cl-effects on a proton translocating ATPase. *J. Membrane Biol.*, 71: 95-105.
- BIDWAI, A.P. & J.Y. TAKEMOTO. 1987. Bacterial phytotoxin, syringomycin, induces a protein kinase-mediated phosphorylation of red beet plasma membrane polypeptides. *Proc. Natl. Acad. Sci. USA*, 84: 6755-6759.
- CHANSON, A., E. MC NANGTHON & L. TAIZ. 1984. Evidence for a KCl-stimulated Mg²⁺ ATPase on the golgi apparatus of corn coleoptiles. *Plant Physiol.*, 76: 498-507.
- CLELAND, R.E. 1987. How hormones work-Auxin and cell elongation, in: *Plant hormones and their role in plant growth and development*. Martinus Nijhoff Publishers, Davies P.J. (ed.), pp. 132-149.
- DE MICHELIS, M.I. & R.M. SPANSWICK. 1986. H⁺ pumping driven by the vanadate-sensitive ATPase in membrane vesicles from corn roots. *Plant Physiol.*, 81: 542-547.
- EWING, N.N. & A.B. BENNETT. 1994. Assessment of the number and expression of P-type H⁺ATPase genes in tomato. *Plant Physiol.*, 106: 547-557.
- HARPER, J.F., L. MANNEY, N.D. DEWITT, M.H. YOO & M.R. SUSSMAN. 1990. The *Arabidopsis thaliana* plasma membrane H⁺ATPase multigene family. Genomic sequence and expression of a third isoform. *J. Biol. Chem.*, 265: 13601-13608.
- HASE, A. 1993. Changes in protein composition and the H⁺ATPase activity of the plasma membrane during induction of callus from tuber tissues of jerusalem artichoke. *Plant Cell. Physiol.*, 34: 67-74.
- HODGES, T.K. & R.T. LEONARD. 1972. Purification of a plasma membrane bound adenosine triphosphatase from corn roots. *Meth. Enzymol.*, 32: 392-406.
- KAUSS, H. & W. JEBLICH. 1985. Activation by polyamines, polycations and ruthenium of the Ca²⁺ dependent glucan synthase from soybean cell. *FEBS lett.*, 185: 226-320.
- KJELLBOM, P. & C. LARSSON. 1984. Preparation and polypeptide composition of chlorophyll-free plasma membranes from leaves of light grown spinach and barley. *Physiol. Plant.*, 62: 501-509.
- OLIVARI, C., M.C. PUGLIARELLO, F. RASI-CALDOGNO & M.I. DE MICHELIS. 1993. Characteristics and regulatory properties of the H⁺ ATPase in a plasma membrane fraction purified from *Arabidopsis thaliana*. *Bot. Acta*, 106: 13-19.
- PALMGREN, M.G. 1991. Regulation of plant plasma membrane H⁺ATPase activity. *Physiol. Plant.*, 83: 314-323.
- PALMGREN, M.G., P. ASKERLUND, K. FREDRIKSON, S. WIDELL, M. SOMMARIN & C. LARSSON. 1990. Sealed inside out and right side out plasma membranes vesicles. Optimal conditions for formation and separation. *Plant Physiol.*, 92: 871-880.
- PARDO, J.M. & R. SERRANO. 1989. Structure of a plasma membrane H⁺ATPase gene from the plant *Arabidopsis thaliana*. *J. Biol. Chem.*, 264: 8557-8562.
- ROLDAN, M., J.P. DONAIRE, J.M. PARDO & R. SERRANO. 1991. Regulation of root plasma membrane H⁺ ATPase in sunflower seedlings. *Plant Sci.*, 79: 163-172.
- SERRANO, R. 1989. Structure and function of plasma membrane ATPase. *Annu. Rev. Plant Physiol. Plant Mol. Biol.*, 40: 61-94.