Anisotropy Parameters for *Chlorophytum* leaf Epidermis

Sergey Savenkov,[1] Ranjan S. Muttiah,[2] Viktor V. Yakubchak,[1] Alexander S. Klimov[1]

[1] *Department of Radio Physics Taras Shevchenko University, Kiev, Ukraine, e-mail: sns@univ.kiev.ua,*

[2] *Depts. Environmental Science & Geology , Texas Christian University, Fort Worth, Texas 7612, USA tel: +1 (817) 257-6272, fax: +1 (817) 257-7789, e-mail: r.muttiah@tcu.edu*

Abstract

Mueller polarization experiments on the epidermis layer of the chlorophytum leaf are presented. Three anisotropy parameters (from among the six) are presented and interpreted.

1 Introduction

Plant leaves have been fine tuned by evolution to capture red and blue photon energy from the sun, transfer electron energy without radiation loss from chlorophyll to chlorophyll molecule to reaction centers, and convert that energy to photosynthetic products. The electric potential required to split water occurs across the thylakoid membrane at these reaction centers. A chlorophyll molecule consists of a porphyrin ring, and a pytol tail. The plane of the poryphyrin ring with respect to the incident electric vector determines the singlet state of the π-orbital electron. In general, the majority of the chlorophyll molecules in mesophyll cells aren't preferentially aligned but rather randomly oriented, except perhaps for the chlorophyll molecules in the PSI and PSII reaction centers [1]. First light must transmit through the leaf surface – which can contain waxes and hairs, and epidermis cells before it reaches the carbohydrate factories in mesophyll cells. Like all plant cells, the epidermis has an outer cell wall providing structural rigidity; buildings are only as good as the strength of their walls. We know much about the biochemical reactions, and atomic scale structures of the molecules regulating photosynthesis [2]. Yet we don't know much about the role that light properties have played in constraining the structure and location of cells and molecules in the leaf. We know from other instances in nature that bees use the polarization of the sky for navigation; UV sensitive rhodopsin is preferentially oriented in specialized microvilli in the dorsal part of the compound eye helping focus and detect plane polarized light. Many other arthropods also seem to use polarization to navigate their way about [3-4].

Do plants control incident light polarization?

2 Method

In order to elucidate the role played by the epidermis cells in controlling light polarization, we performed Mueller polarimetry experiments as shown in Fig.1. The laser beam (λ = 630 nm) was normally transmitted through the epidermis layer and imaged on a 512 x 512 CCD camera after microscopic magnification. Epidermis layers from the mid-section were mechanically separated from *Chlorophytum* leaves, and experiments repeated for 10 samples. The polarimeter consisted of two main parts: sensing channel and receiving channel. The sensing channel produced incident radiation in various states of polarization: a source of electromagnetic radiation with isotropic (completely unpolarized or circularly polarized) polarization 1, ideal polarizer and quarter-wave phase plate 3, both with computer controlled azimuth of orientation. The receiving channel represented an arrangement for Stokes vector components (Stokes-polarimeter 5): a continuously turning quarter-wave phase plate, fixed analyzer, and, photodetector (number 7). The six parameters characterizing anisotropy and depolarization of epidermis

were generated from the inverse polarimetric technique given in Savenkov et al. [5-6]: Δ ($0 \le \Delta \le 2\pi$) is the phase shift between two orthogonal linear components of electric vector of incident light, α ($0 \le \alpha \le 2\pi$) is the azimuth of linear phase anisotropy (linear birefringence), φ ($0 \le \varphi \le 2\pi$) is the phase shift between two orthogonal circular components of incident light or measures circular phase anisotropy (circular birefringence), P ($0 \le P \le 1$) is the relative absorption of two linear orthogonal polarizations, and γ ($0 \le \gamma \le 2\pi$) is the azimuth of linear amplitude anisotropy (linear dichroism); R ($-1 \le R \le 1$) is the relative absorption of two orthogonal circular polarizations of circular amplitude anisotropy (circular dichroism). Finally entropy [7] which characterizes depolarization was calculated. For additional details on entropy derivation, the reader is referred to [7].

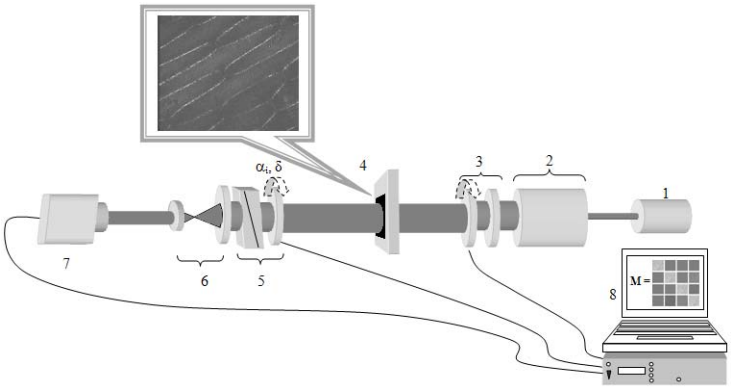

Figure 1: Polarimeter setup.

We present results for P, γ, and Δ [5].

3 Results & Discussion

Figure 2a shows the linear dichroism P: the cell walls have about equal absorption for both components of electric vector, where as, the cell cytosol and vacuole absorbed one of the electric vectors. Figure 2b, which shows the orientation γ of linear dichroism, suggests random orientation (or size) except on cell wall, except along the cell wall. Figure 3a for linear birefringence Δ is due to the differences in the chemical make up of the cell wall and cytosol/vacuole. From entropy (Figure 3b), we surmise light goes directly through the cytoplasm of the cells without being multiply scattered inside the cell i.e., the polarization state of the preferentially absorbed electric vectors is not altered. The poincare sphere (Figure 3c) for leaf without the epidermis (generated from a separate experiment) showed that relative to the epidermis, the internal cells in the leaf were highly depolarizing the incident light: once the electric vector (either E_x or E_y, but not both) entered the inner leaf, it was multiply scattered/absorbed. Figure 4 shows a more magnified view of the epidermis cells. The cell walls are composed of a plasma membrane on the surface of which a primary network of cellulose cross linked with glycans forms microfibrils which is embedded in a secondary network of pectic polysaccharides, which in turn is inside a structural protein or phenylpropanoid network [1]. The pectin matrix regulates wall porosity, and cellulose synthesis occurs *outside* the plasma membrane. The proteins, pectins and other other chemicals for the secondary and tertiary networks are synthesized inside the cell in the endoplasmic reticulum, and golgi apparatus which are then exported to the surface in vesicles. The tiny specks in Figure 4 likely shows the vesicles, golgi apparatus, or the endoplasmic reticulum. Our results open up an interesting discussion. The cell walls are very thin, not more than 100 nm. Our results suggest that the epidermis cytoplasm does control the polarization state of incident light.

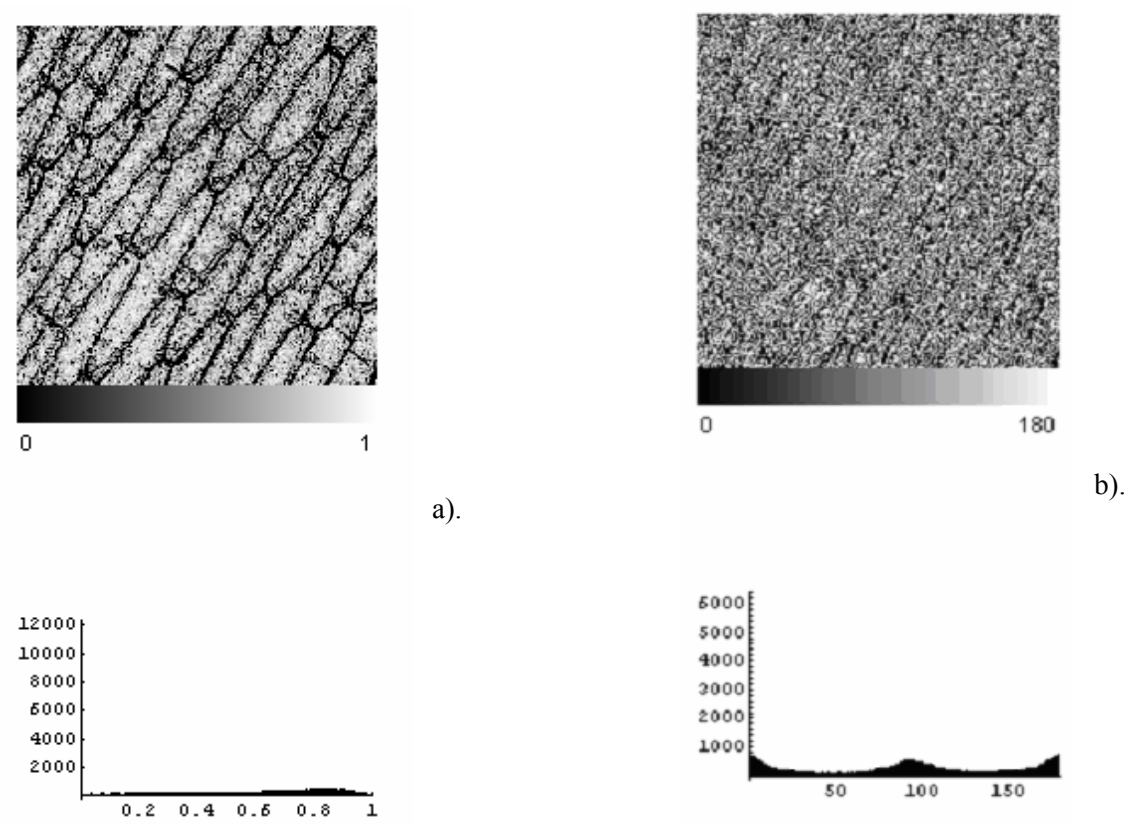

Figure 2a: Dichroism parameter and histogram of values; b: angle of dichroism and histogram for light transmission through epidermis.

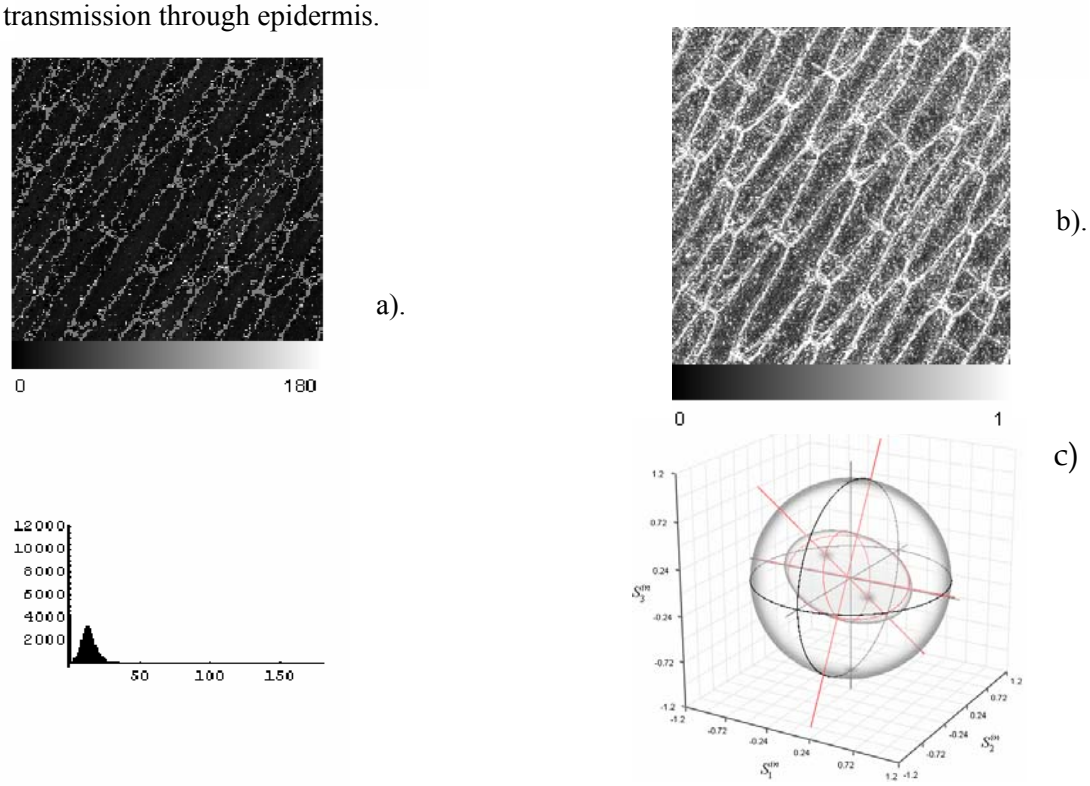

Figure 3a: Phase shift for linear anisotropy; b: Entropy, and c: Poincare sphere (the outer sphere represents incident light) for leaf without epidermis.

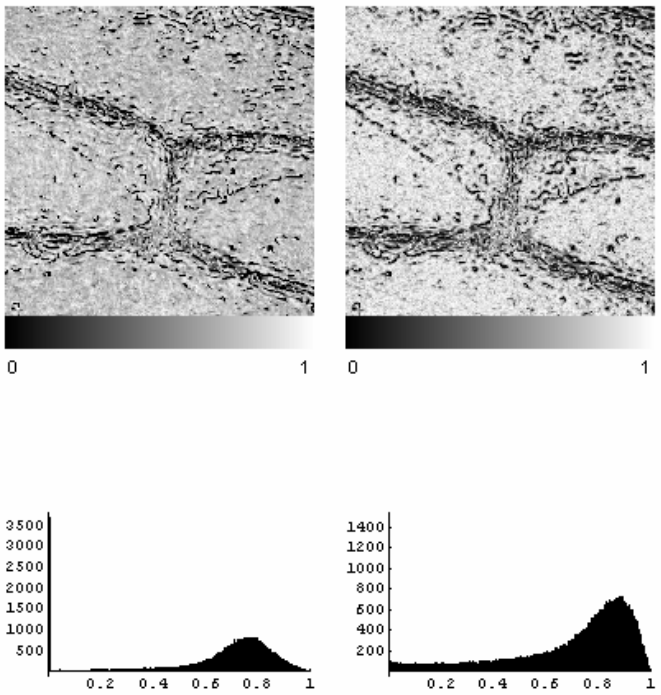

Figure 4: Magnified view of the area between two epidermis cells for amplitude of linear polarization anisotropy; the histogram of values is shown below.

4. Conclusion

Our polarization experiments are the first ever observations on the polarization optics of leaf epidermis. It is highly likely that the epidermis "filters" the incident sunlight to a specific polarization state.

References

[1] P. S. Nobel, Biophysical Plant Physiology and Ecology, W.H. Freeman & Co, New York (1983).

[2] B.B. Buchanan B.B., W. Gruissem, and R.L. Jones, Biochemistry & Molecular Biology of Plants, American Society of Plant Physiologists, Rockville, Maryland (2000).

[3] R. Wehner, "Ant's celestial compass system: Spectral and polarization channels" In: Orientation and Communication in Arthropods (Ed., M. Lehrer), pp. 145-185, Birkhauser-Verlag, Berlin (1997).

[4] M. Dacke, D.-E.,Nilsson, E.J. Warrant, A.D. Blest, M.F. Land, and D.C.O'Carroll. Built-in polarizers form part of a compass organ in spiders. Nature **401**: 470-473, 1999.

[5] S.N. Savenkov, V.V. Mar'enko, E.A. Oberemok and O.I. Sydoruk, "Generalized matrix equivalence theorem for polarization theory," Phys. Rev. E **74**, 056607 (2006).

[6] S.N. Savenkov "Optimization and structuring of the instrument matrix for polarimetric measurements," Opt. Engineering. **41**, 965-972 (2002).

[7] S.R. Cloude, "Groupe theory and polarization algebra," Optik **75**, 26-36 (1986).