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Do Angiosperms Learn Lessons from Life? [1,2]

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KEYWORDS

Taraxacum officinale, common dandelion, environmental scanning electron microscopy (ESEM), plant learning, memory, growth, development.

INTRODUCTION

Scant attention has been paid to the phenomenon of learning by plants. Some preliminary experiments have shown that *Taraxacum* responds to stimuli remembered from an earlier growing season. Microscopy throws further light on the histological changes that underpin the phenomenon.

How *Taraxacum* responds

The common dandelion, *Taraxacum officinale* (L) is a springtime flowering European plant. Coarsely serrated edible leaves form a rosette from the centre of which foot-high stems are produced. At the end of each is a circular inflorescence of a deep yellow hue, typical of the Asteraceae to which *Taraxacum* belongs. As the seeds set, each flower head is replaced by a spherical, feathery mass of seeds which are borne aloft by a lightweight cypsela that functions like a parachute.

Not all *Taraxacum* plants grow as tall, however. After the elongated flowering stems have been severed, subsequent stems are greatly restricted in size. Under natural conditions, the flowering stems of each mature *Taraxacum* plant measure up to 350 mm in length, but plants can readily learn to modify this. They have a sense that has not previously been documented.

The fact that angiosperms can thus respond to trauma is not appreciated by modern bioscience, but the mechanisms of plant learning could help us in fields that range from computer design to pest control. We know that the seedbearing vascular plants (Spermatophyta) are able to respond to alterations in their environmental conditions, and it is still widely accepted that we have much yet to learn about plant sensation and response. The responses of plants to pesticides is being actively pursued, as is research into genetic modification.

One crucial aspect of plant behaviour has been little studied—the question of a plant's ability to learn. Previously unknown angiosperm learning mechanisms are the core of this topic. The change in morphology seen in *Taraxacum* is not a short-term response to a perceived stimulus. It takes place over time. The plants seem to be remembering a traumatic experience and recalling information in the future.

Plant responses in nature

For research, the chosen experimental subject has been *Taraxacum officinale,* the common dandelion. Known as an invasive weed species throughout the southern United Kingdom, *Taraxacum* plants can produce edible salad leaves. A dandelion meadow is an unusual sight in Britain, but is relatively common in Eastern Europe.

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1 Presented at Inter Micro 2006, Chicago, Illinois.
2 The research was first outlined at Rothamsted Research, Harpenden, England, on October 13, 2005

Taraxacum plants are severed near ground level when a meadow is mown. All flowering stems are removed. We observe that the plants continue to flower even after the mowing has been completed. However, the plants have apparently adjusted their rate of growth in response to the assault: the flowers seem to learn to protect themselves. Instead of standing tall and erect, they produce inflorescences with shorter stems. Furthermore, each stem does not seem to rise upright, but to keep closer to the ground. In this mode the flowering stems are less likely to be cut.

We know that flowers can follow the sun, undergo sleep movements and make rapid touch responses. These are due to very large changes in K^+ and Ca^+ movements into and out of specialised motor cells. This modulates pressure within the motor cells, thus causing the plant to change its posture. However, there are many questions that remain. How are tactile stimuli passed to the relevant motor structures? Calcium plays a crucial part in the proceedings. For example, calcineurin is one of the main substances involved in these motor changes. We still need to understand how it operates. What is the role of calcium regulators like calmodulin, and frequenin, which has four Ca^{2+} binding regions? There is much we have to learn.

Experimental observation

Taraxacum plants over-winter with little visible leaf production, and are sustained through reserves of nutriment stored in the tap-root that is typical of the group. When temperatures exceed 10°C as the equinox is reached, rapid elongation of the flower stem is observed. Mature plants of *Taraxacum officinale* growing in the wild under natural conditions were taken as the benchmark. Rapid elongation of the stem takes place within one month as the spring growing season commences.

The *Taraxacum* plants in late March 2005 showed little leaf growth above ground, other than a modest rosette that may be observed throughout the winter months. During April the growth season starts; the equinox has past and temperatures are above 10°C. Within a month the flowering stem is fully extended and typically reaches 300 mm in length.

In plants subject to regular cutting during the previous season, the characteristic crown of toothed leaves has much the same appearance as an unconstrained plant. This specimen has been subject to regular cutting throughout the summer and was cut during dry days of the autumn and winter. The leaves are similar in size to a wild plant; however, even after one month of growth, flowering stems are produced in which elongation is greatly inhibited, and final flowering stem length is restricted to <50 mm. Plants have learned from the trauma of severance during the previous season and—even after a six-month interval—restrict stem length to one-third normal (about 100 mm).

The tallest plants are found in undergrowth. With the etiolation that can be imposed when surrounding vegetation is dense, stem length can exceed 500 mm. However, even when plants have not experienced cutting for 26 weeks, memory mechanisms cause them to restrict flowering stem elongation to less than one-third the normal length. Specimens from plants that had been subject to regular cutting show maximal foreshortening, in some cases to one-tenth the dimensions observed in unconstrained *Taraxacum* plants. These observations show that plants of *Taraxacum* can produce flowering stems of remarkably different overall dimensions that are clearly related to prior experience.

Final dimensions of the stems in a mature plant are proportional to the time that has elapsed since the plant experienced severing at the base of the stems, and there seem to be long-term memory mechanisms at work. We can see this in plants in which the last severing trauma had been 26 weeks earlier. Even in these specimens we can observe marked inhibition of stem elongation. Plants reveal some degree of proportionality: these flowering stems reach a height of approximately one-third of the normal value in response to a traumatic stimulus remembered from six months earlier. There can be only one conclusion: these plants have memory and utilise it to good effect.

Histological results

Optical and variable-pressure scanning electron microscopy can throw light on the mechanisms that *Taraxacum* utilizes to regulate stem length. Section material was prepared from fresh *Taraxacum* stems in full-growth and compared with sections cut from foreshortened stems.

The light microscope produced a clear impression that, although the diameter of the cells remained relatively constant, cell elongation was clearly restricted in the foreshortened stems. This is not caused by reduced mitotic growth, for microscopy reveals that it results from a reduction in growth by vacuolation. In general terms, it seems that the cell population remains the same in foreshortened and in elongated flowering stems. In the shorter stems, although the diameter of the cells remains similar, the cells are foreshortened, and in consequence so is the entire stem.

How does *Taraxacum* restrict stem elongation? What occurs within modified stems? Could a reduction in turgor pressure provide an explanation for these phenomena? This would be an effective way for a plant to regulate cell volume, and this mechanism is found elsewhere in the plant world. However, this would clearly result in a reduction in cell diameter proportional to cell length, and we do not observe this in the case of stems of *Taraxacum*.

It may be that there are specific factors that regulate elongation and which do not affect cell diameter. High-power environmental scanning electron microscopy (ESEM) reveals thickening within the cell walls. At higher magnifications, annular features are observed which may mediate the extent to which a cell can physically elongate in two directions. It may transpire that these physical constraints in the design of the cell underpin the elongation process. Since the sculpturing is invariably annular, never longitudinal, it will restrict changes in cell diameter and alterations in volume will become manifest in changes in cell length, and thus will regulate the length of the entire stem.

We have factors at work that could have wide-ranging effects in plant science. There is clear evidence that these microscopical changes are related to stimuli that have been retained in the plant memory for many months, and this adds additional layers of complexity to this intriguing new field of scientific investigation.

SUMMARY

The light microscope leads us to conclude that stem elongation control in *Taraxacum* is related to previous experience of cutting. The more frequently (or the more recent) a flowering stem has been removed by cutting, the greater the restriction applied to stem elongation in new growth. Since the stems are rapidly produced in spring, we can deduce that the elongation is due to growth by vacuolation rather than to changes in mitotic proliferation, and this is confirmed by microscopy. The stem epidermis shows marked alterations in appearance of cell structure in normal and attenuated states. Under the Environmental Scanning Electron Microscope (ESEM) at the Cavendish Laboratory, Cambridge, England, it has been possible to obtain images of the living cells under both conditions.

Preliminary research demonstrates that *Taraxacum* can apparently modify its growth habit in response to traumatic stimuli. Plants subject to regular cutting produce stems of markedly restricted growth which may reduce them to 10% of the length observed in wild and unconstrained specimens. Remarkably, it has been shown that plants produce stems that are significantly reduced in length many months after traumatic stimuli have ceased.

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Preliminary observations were published in:

Ford, Brian J., 1998, *Die Geheim Sprache der Natur - Wie Tiere und Pflanzen sich verständingen*, ISBN 3-216-30366-7, Wien-München: Deuticke.

———, 1998, *Czujace Istoty, zmysly i emocje roslin, zwierzat i mikroorganizmow,* ISBN 83-7169-796-1, Warsaw: Wydawnictwo Amber.

———, 1999, *Sensitive Souls – Senses and Communication in Plants, Animals and Microbes*, ISBN 0 316 63956 7, London: Little, Brown.

———, 2001, 蒲公英的記憶：動物、植物和微生物的感覺與溝通, ISBN 957-469-380-5, Taiwan: Owl Publishing House.

———, 2003, *Czujace Istoty, zmysly i emocje roslin, zwierzat i mikroorganizmow,* NR 10327, Lithuania: Vilnius.

——— , 2000, *The Secret Language of Life, How Animals and Plants Feel and Communicate*, 320pp, ISBN 0 88064 254 8, New York: Fromm International.

Appendix:
Figures Illustrating Memory-induced Inhibition in Taraxacum

Figure 2. The Taraxacum plants in late March 2005 showed little leaf growth above ground, other than a modest rosette that may be observed throughout the winter months.

Figure 1. Meadows of Taraxacum are a common sight around the vernal equinox in Eastern Europe, and occasionally in East Anglia, UK.

Figure 3. During April the growth season starts; the equinox has past and temperatures are above 10^0C. Within a month the flowering stem is fully extended (left) and typically reaches 300 mm in length (right).

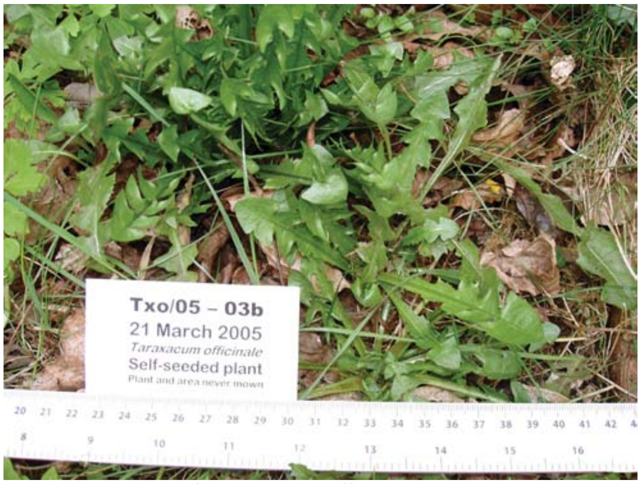

Figure 4. Plants of Taraxacum officinale over-winter with little growth visible above ground. A modest leaf rosette persists throughout much of winter.

Figure 5. In plants subject to regular cutting during the previous season, the characteristic crown of toothed leaves has much the same appearance as an unconstrained plant.

Figure 6. This specimen has been subject to regular cutting throughout the summer and is cut during dry days of the autumn and winter. The leaves are similar in size to a wild plant.

Figure 7. After the equinox, plants enter a rapid spurt of growth. New leaves are produced, and the flowering stem soon exceeds 300 mm in height.

Figure 8. Plants have learned from the trauma of severance during the previous season and—even after a six-month interval—restrict stem length to one-third normal (about 100 mm).

Figure 9. One month of growth produces flowering stems in which elongation is greatly inhibited. The more recent memory restricts final flowering stem length to <50 mm.

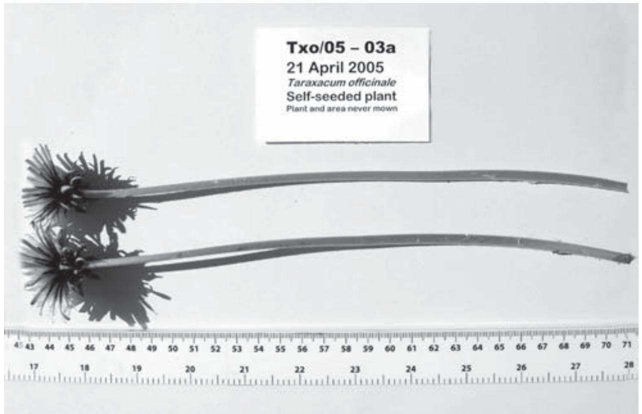

Figure 10. Typical isolated flowering stems from wild-state Taraxacum. With the etiolation that can be imposed when surrounding vegetation is dense, stem length can exceed 500 mm.

Figure 11. Even when plants have not experienced cutting for 26 weeks, memory mechanisms cause them to restrict flowering stem elongation to less than one-third the normal length.

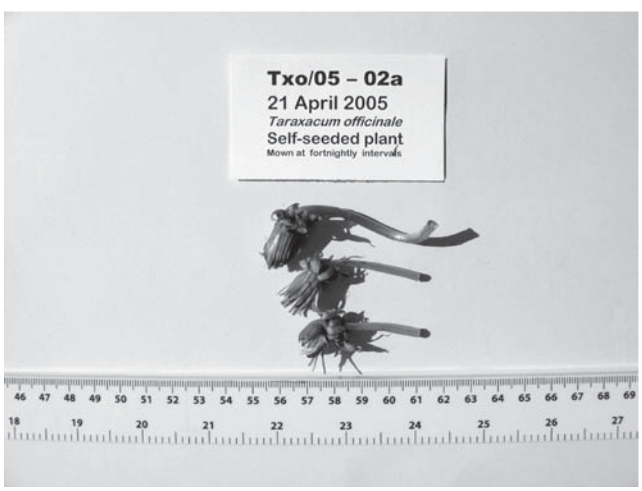

Figure 12. Specimens from plants that are subject to regular cutting show maximal foreshortening, in some cases to one-tenth the dimensions observed in unconstrained Taraxacum plants.

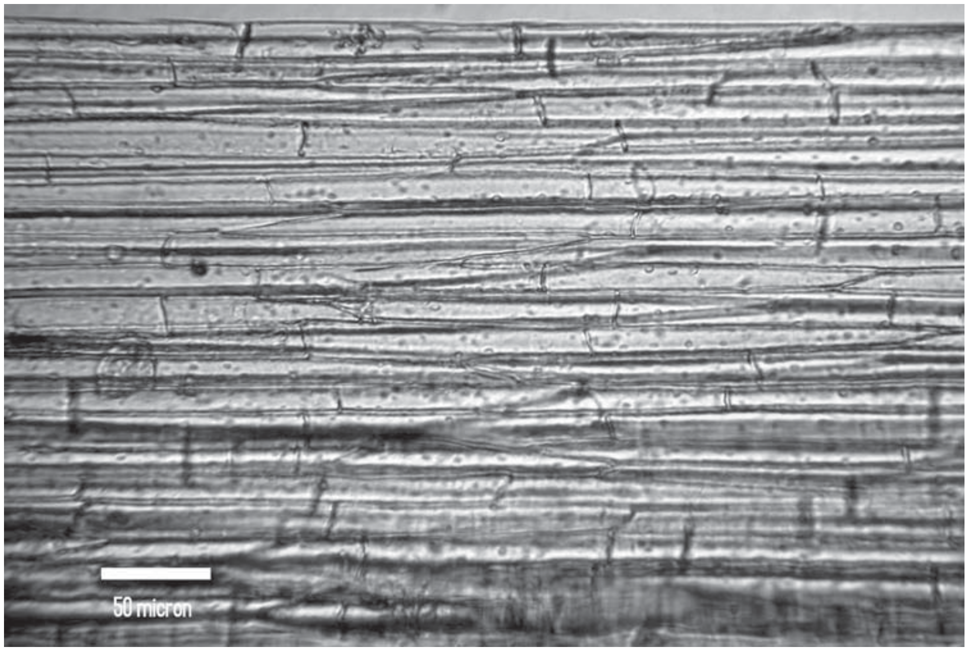

Figure 13. Longitudinal section of normal Taraxacum stem under brightfield microscopy.

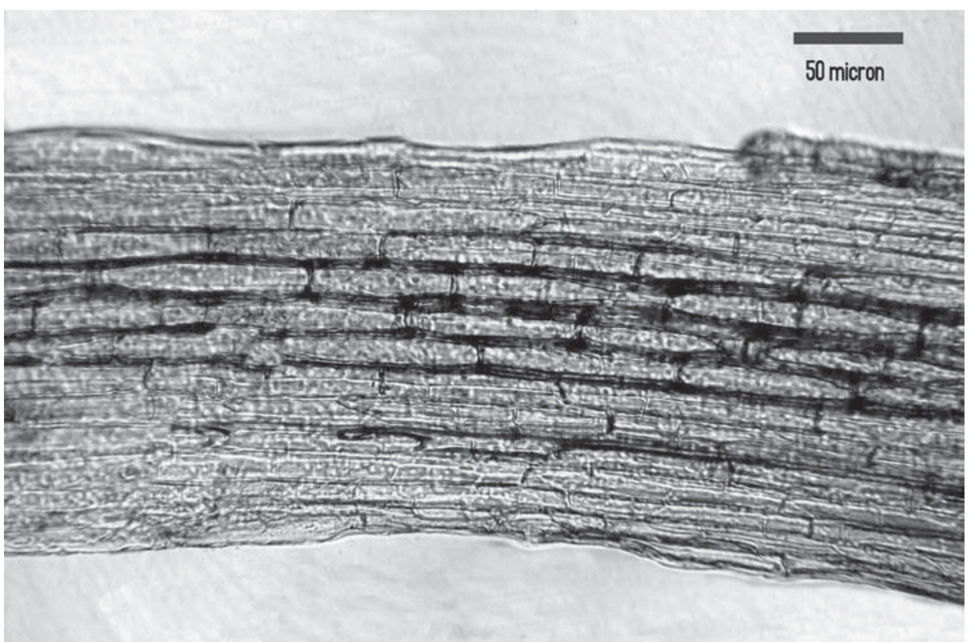

Figure 14. Histology is markedly different in the case of foreshortened Taraxacum stems. Growth by vacuolation in the cortical cells is restricted.

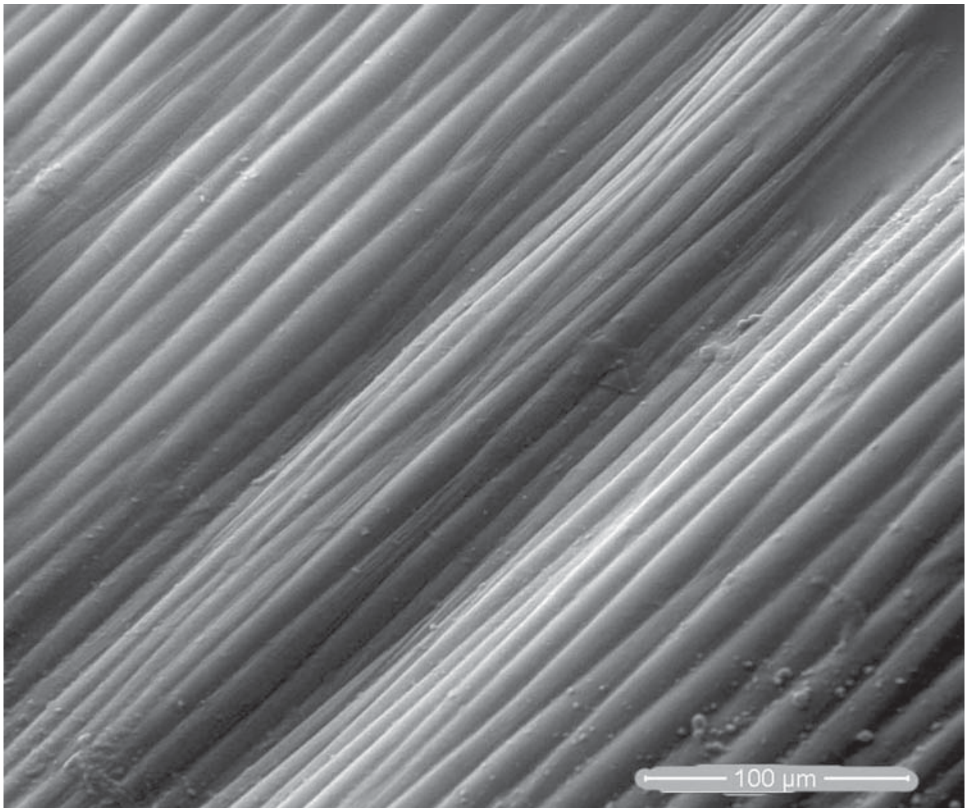

Figure 15. Grossly elongated epidermal cells typify the surface structure of Taraxacum growing under wild conditions, ESEM.

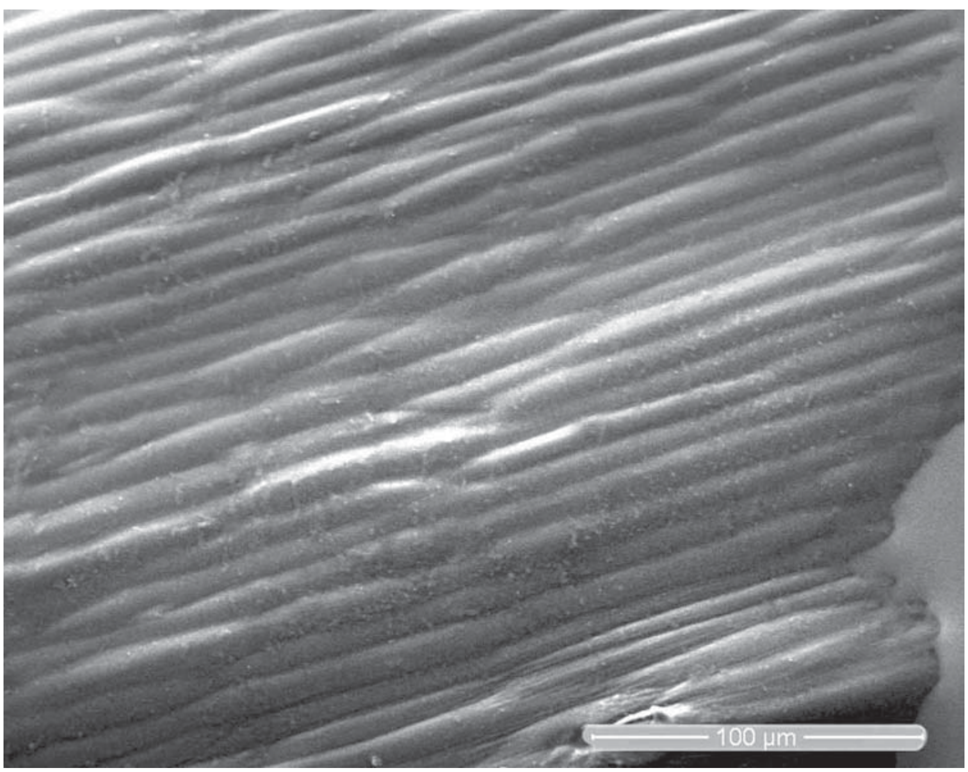

Figure 16. Variable-pressure scanning electron microscopy in the Environmental Scanning Electron Microscope (ESEM) reveals marked foreshortening of epidermal cells in stem specimens taken from foreshortened plants.

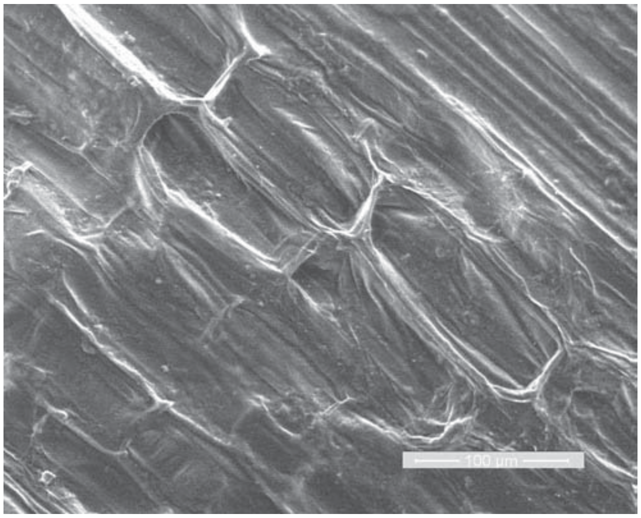

Figure 17. Attenuated cortical cells observed under the ESEM at the Cavendish Laboratory, Cambridge.

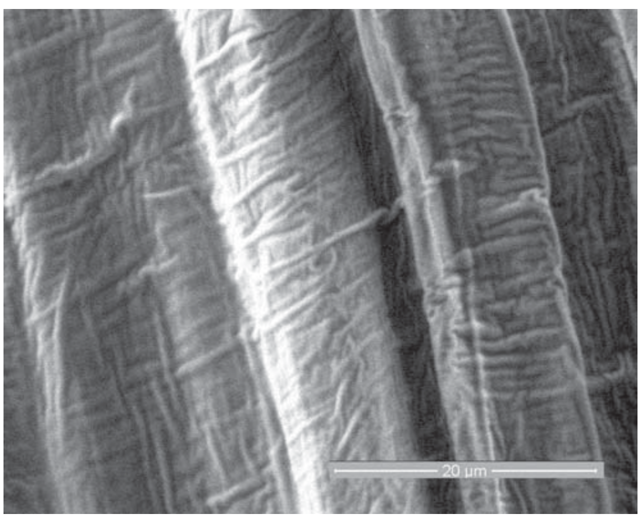

Figure 18. The nature of the sculpturing of the cells' walls varies and further research should elicit the reason, ESEM.

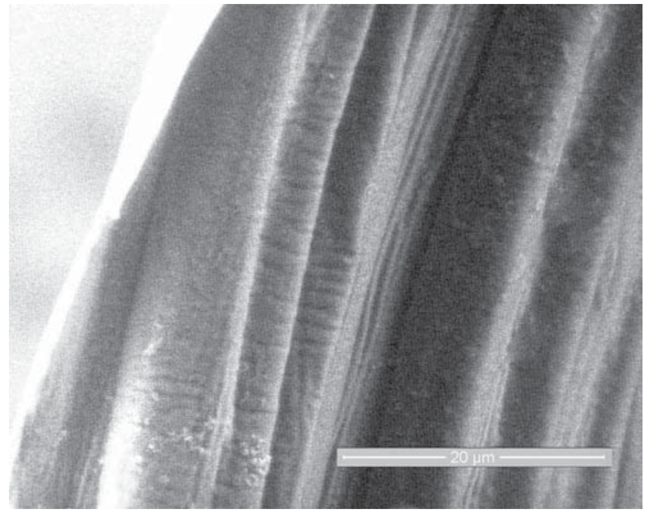

Figure 19. Annular thickening may constrict elongation in a cell subjected to varying levels of turgor pressure, ESEM.

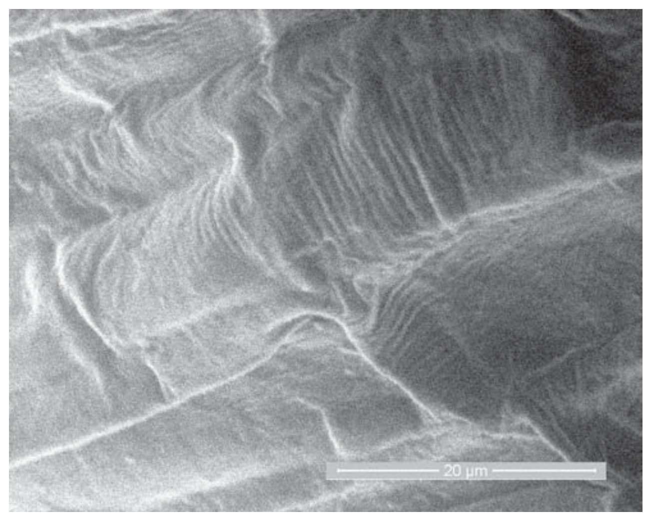

Figure 20. Sculpturing is invariably annular, never longitudinal, which may regulate stem growth patterns, ESEM.