Action Potentials in the Venus Fly Trap

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The Venus Flytrap, *Dionaea muscipula* Ellis, is endemic to North and South Carolina, extending a 60-75 mile radius around Wilmington, N.C. (Schnell 1976; Schwartz 1974). The plant consists of a rosette of leaves emanating from a central rhizome. The leaves consist of a narrow to broad leaflike petiole near the rosette center with a leaf blade modified into a unique trap (Lloyd 1942; Schnell 1976). The trap is bilaterally symmetrical with the two lobes separated by an angle of approximately 45-60 degrees (Benolken, *et al* 1970; Lloyd 1942; Schnell 1976). Each lobe contains three or more trigger hairs placed in a triangular position (Darwin 1875; Lloyd 1942; Schnell 1976; Slack 1979; Benolken, *et al* 1970).

The sensory hair is 2mm in length and 200 microns in diameter. The fine structure of the trigger hair consists of two distinct sections. The outer cone of thick-walled cells is called the lever and the 4-5 courses of cells joining the trap surface on which the lever sits, the podium (Lloyd 1942; Williams, *et al* 1971). These4-5 courses of cells are termed, "the indentation," by Williams, and "sensitive cells," by Lloyd.

The closing response, whether initiated by mechanical, chemical, electrical or thermal stimulation of the trigger hairs, results in the production of action potentials. A minimal requirement for closure is that one sensory hair be mechanically stimulated twice or two different hairs be stimulated simultaneously (Balotin, *et al* 1962; Brown 1910; Brown, *et al* 1916; Darwin 1875; Jacobson 1965; Lloyd 1942; Schnell 1976; Schwartz 1974; Slack 1979). At higher temperatures, i.e. thermal stimulation, the trap responds to one stimulus if the hair is bent (Brown 1910). Closure can also be induced chemically with 3% saline as investigated by Balotin, *et al* 1962.

The existence of action potentials upon stimulation of the sensitive trigger hairs has been investigated and confirmed by various authors. Shuhlman O., Jr. and Darden, E.B. 1950, observed a diphasic action potential consisting of a short-lived positive electrical increase followed by a larger negative rise and fall in potential. A positive after potential follows with restoration occuring within 1.5 seconds.

DiPalma, J.R. 1961, determined that two successive stimuli are necessary to cause contraction. The first action potential was ineffective and elicited a slower depolarization rate than the second action potential which resulted in trap closure. Quantitatively, the duration of the negative phase was experimentally determined to be 0.13 seconds as compared to the first action potential of 0.24 seconds. Apparently for the excitatory process to initiate contraction, the rate of depolarization must attain a certain velocity. Buchen, B. *et al* 1983, quantified this velocity to be 20 cm/second.

The plasmalemma resting potential was recently determined to be -80mV. This resting potential is subsequently depolarized to a graded, non-propagated receptor potential, followed by an action potential of about +80mV which propagates to the motor cells with a velocity of 20 cm/sec. Alterations of the membrane potential may be mediated by differential gradients which lead to turgor changes and ultimately trap closure (Buchen, B., *et al* 1983). Morphologically, the apical and basal cell poles of the sensory cells in the trigger hairs of the Venus Flytrap are structurally identical. A complex of concentrically arranged endoplasmic reticulum cristernae occupies each of the poles. One to four vacoules are enclosed within the central cisterna and contain polyphenols. The role of these polyphenolic compounds in the sensory cells can be considered as storage, binding, and release of ions which are necessary for the electrochemical processing of stimulus transduction (Buchen, B., *et al* 1983).

Balton, M.N. and DiPalma, J.R. 1962, investigated that both mechanical and chemical stimulation of the trigger hairs results in the production of action potentials with subequent trap closure. Mechanical stimulation of the trigger hairs results in a single action potential. The instillation of 4 to 6 drops of 3 percent sodium chloride solution in the leaf trap of *Dionaea muscipula* results in a series of spontaneous action potentials and trap closure. The action potentials were highly variable with respect to frequency and duration. An amplitude of 20-30 mV with a 2 to 4 second duration was observed. The pulse frequency of the action potentials were 2 to 4 pulses per minute with a total duration of one minute to several hours. Variations seen in the action potentials were due to positioning of the electrodes, health, age of plant, temperature, and intensity of stimulus. The mechanism of closure is believed to be linked to a positive loss of turgor in the leaf trap upon stimulation of the sensitive hairs. This results in the sudden reduction in hydrostatic presssure of the cells of the inner epidermis through depolarization.

Affolter, J.M. and Olivo, R.F. 1974, observed the presence of long term action potentials following the capture of prey. The investigators placed a live Isopodia (pill bug) inside the trap and monitored the action potentials for the first two hours. Over one hundred sporadic action potentials were recorded from this trap as a result of repeated stimulation of the trigger hairs by the struggling prey. Evidently the prey is not necessarily killed immediately after it has been trapped. Repeated stimulation of the trigger hairs by the active prey therefore results in action potentials thus causing the trap to tighten further. These continued action potentials also stimulate the digestive glands of the plant to begin secretion. The juices expressed by the compression of the leaf, or exuded during the struggle, have an effect similar to 3% saline. The juices of a leaf that contained an insect for 48 hours will, if instilled on another leaf, cause spontaneous electrical activity and subsequent closure of the trap.

DiPalma, *et al* 1966, investigated numerous small structures (stellate trichomes) protruding from the surface of marginal hairs, outer leaf surface and stem of *Dionaea muscipula.* None of these structures is present inside the trap nor among the trigger hairs. Mechanical stimulation of the stellate trichomes results in the production of small action potentials and eventual closure of the trap, independent of the sensitive trigger hairs. Stellate trichomes are microscopic and at a magnification of 100x they resemble small rosettes. There are generally eight hair-like petals of non-cellular translucent material radiating from a central spindle, with an overall diameter of 80 microns. Subthreshold stimulation of these structures appears to sensitize the trigger hairs and facilitate closure of the trap. Approximately 8 to 10 strokes of a brush across the outer surface to the trap elicited the first action potential, after which a small non-propagated potential arose after each stroke. The trap contracted when 5 or 6 full action potentials were propagated by the stellate trichomes.

The stellate trichomes may therefore serve as touch receptors that are capable of altering the internal environment of the trap thus rendering it more susceptible to closure by deflection of the trigger hairs.

The Venus Flytrap, "the most wonderful plant in the world," is truly a marvel of nature. Its unique ability of producing action potentials and digestion of insects, with subsequent absorption of nutrients, has indeed fascinated man for centuries.

Note: *The author invites you to contact him if you wish to read any of the cited literature.*

Literature Cited

1. Affolter, J.M. and Olivo, R.F. 1975. *Action potentials in long term observations following the capture of prey.* Amer. Midland Naturalist 93: 443-445.
2. Balotin, N.M. and DiPalma, J.R. 1963. *Spontaneous electrical activity of* Dionaea muscipula. Science 138: 1338-1339.
3. Benolken, R.M. and Jacobson, S.L. 1970. *Response properties of a sensory hair excised from Venus's Flytrap.* J. Gen. Physiol. 56: 64-82.

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ACTION POTENTIALS, continued from page 17.

4. Brown, W.H. 1916. *The mechanism of movement and the duration of the effect of stimulation in the leaves of* Dionaea. Amer. J. Bot. 3: 68-90.
5. Brown, W.H. and Sharp, L.W. 1910. *The closing response in* Dionaea. Bot. Gaz. 49: 290-302.
6. Buchen, B., Hansel, D., and Sievers, A. 1983. *Polarity in mechanoreceptor cells of trigger hairs of* Dionaea muscipula. Planta 158: 458-68.
7. Darwin, C. 1875. *Insectivorous Plants* D. Appleton & Co. New York. pp. 286-320.
8. DiPalma, J.R., Mohl, R. and Best, W. Jr. 1961. *Action potentials and contraction of* Dionaea muscipula *(Venus Flytrap).* Science 133: 878-879.
9. DiPalma, J.R., McMichael, R. and DiPalma, M. 1966. *Touch receptor of the Venus Flytrap,* Dionaea muscipula. Science 152: 539-541.
10. Jacobson, S.L. 1965. *Receptor response in Venus's Flytrap.* J. Gen. Physiol. 49: 117-129.
11. Lloyd, F.E. 1942. *The Carnivorous Plants.* Chronica Botanica Co. Waltham, Mass. 177-194.
12. Schnell, D.E. 1976. *Carnivorous Plants of the United States and Canada.* (John F. Blair publisher) Lebanon Valley Offset Co. Inc. North Carolina. pp. 16-21.
13. Schwartz, R. *Carnivorous Plants.* 1974. Avon Publishing Corp. Chicago. pp. 14-18.
14. Slack, A. *Carnivorous Plants.* 1979. MIT Press, Mass. pp. 155-160.
15. Stuhlman, O. and Darden, E.B. 1950. *The action potential obtained from Venus's Flytrap.* Science. 111: 491-492.
16. Williams, M.E. and Mozingo, H.N. 19711971. *The fine structure of the trigger hair in Venus's Flytrap.* Amer. J. Bot. 58(6): 532-539.