The Role of ATP in Mechanically Stimulated Rapid Closure of the Venus’s-Flytrap

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ABSTRACT

When the midribs of untreated traps of Dionaea muscipula are frozen in liquid nitrogen after rapid closure, they contain significantly less ATP than those frozen before closure. Exogenous ATP causes a significant increase in the rate of mechanically stimulated trap closure. Illuminated traps close faster than those kept in the dark. The traps of plants placed in 100\% O2 close much faster than do air controls, while 100\% CO2 inhibits closure. It is concluded that ATP is probably the native source of potential energy for contraction of the trap’s midrib, and that if the endogenous ATP titer is increased by oxidative phosphorylation or an exogenous source, the trap will close faster.

MATERIALS AND METHODS

Bulbs of Dionaea muscipula (Venus’s-flytrap) were obtained from Carolina Biological Supply Co., Burlington, North Carolina and grown in well drained peat moss in plastic pots.

Table I. Effects of Various Treatments on the Rate of Trap Closure (Midrib Contraction) of Mature Traps of Dionaea muscipula

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Trap Closure$^1$ (degrees per second)</th>
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</thead>
<tbody>
<tr>
<td>Pretreated for 20 hr in the dark, then, prior to mechanical stimulation, held for 30 min in the air in:</td>
<td></td>
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<tr>
<td>Darkness</td>
<td>39 ± 19</td>
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<tr>
<td>Light</td>
<td>129 ± 37</td>
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<tr>
<td>Following a pretreatment in the dark in the same atmosphere for 30 min, stimulated in the dark in:</td>
<td></td>
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<tr>
<td>Air (0.03% CO2, 20.5% O2)</td>
<td>20 ± 2</td>
</tr>
<tr>
<td>100% CO2</td>
<td>2 ± 0</td>
</tr>
<tr>
<td>100% O2</td>
<td>82 ± 30</td>
</tr>
<tr>
<td>Stimulated in the dark under standard conditions after 30-min topical pretreatment on the midrib with aqueous solutions (containing 0.01% Tween 20) of:</td>
<td></td>
</tr>
<tr>
<td>Water (control)</td>
<td>40 ± 5</td>
</tr>
<tr>
<td>100 \muM AMP</td>
<td>34 ± 9</td>
</tr>
<tr>
<td>100 \muM ATP</td>
<td>55 ± 8</td>
</tr>
</tbody>
</table>

$^1$ N = 20; LSD at 5\% c = 7.

One bulb was planted per pot and, during use, each plant usually had from two to five usable traps. The traps were considered mature when they opened fairly flat and the upper surface was a bright red color. The experiments testing the effects

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RESULTS AND DISCUSSION

It normally took a trap less than 1 sec to close completely and less than 24 hr to open and be ready to be mechanically stimulated and close again. The midrib could not go through more than two or three successive contractions and recoveries.

The effects of various pretreatments on the rate of mechanically stimulated trap closure is shown in Table I. After a prolonged dark period, the traps closed over three times more rapidly in the light than in the dark. In 100% CO\textsubscript{2}, the traps closed only one-tenth as rapidly as in air, whereas in 100% O\textsubscript{2}, they closed four times faster than in the air control. Although pretreatment with AMP did not appreciably change the rate of trap closure, a 30-min topical application of 100 \textmu M ATP caused a significant increase in contraction of the midrib. It might also be noted that the effects of the latter addendum on recovery (opening) of the trap were to produce average rates of 39, 37, and 55° per 24 hr, after treatments with water, AMP, and ATP, respectively.

Further indication that ATP is involved in the energetics of contraction (closure) of the trap midrib is shown by the measurement of endogenous ATP before and after stimulation and closure. There was 950 ± 40 \textmu M ATP per midrib in midrubs obtained before stimulation, whereas after stimulation and closure, the amount of ATP per midrib was 650 ± 50 \textmu M. The least significant difference at 5% was 29, and so the two values were significantly different from each other.

The main observations made in the present study are that mechanically stimulated contraction of the trap midrib of Dionaea muscipula produces a dramatic drop in the endogenous titer of ATP, and that added ATP or environmental treatments which would tend to increase the natural ATP level, also cause an increase in the rate of closure of the trap. Thus, increasing the O\textsubscript{2} content of the air increases the rate of trap closure, whereas removing O\textsubscript{2} and increasing the CO\textsubscript{2} level, decreases it. These observations indicate that ATP is a native source of energy for the closing process, a conclusion supported by similar data reported for other mechanically stimulable rapid plant movements such as pea tendrils (3, 5) and the primary motor pulvinus of Mimosa pudica (8). The mechanism which uses ATP to produce such rapid movements is not known. However, the Mimosa and tendril systems are known to contain contractile actomyosin-like ATPase (4, 11) which, at least in the case of the pea tendrils, becomes less active as contraction of the organ progresses (4). Thus, it may be that a similar ATPase also exists in the trap midrib of D. muscipula and is involved in the closing mechanism.

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LITERATURE CITED