Sequence similarity between Photosystems I and II. Identification of a Photosystem I reaction center transmembrane helix that is similar to transmembrane helix IV of the D2 subunit of Photosystem II and the M subunit of the non-sulfur purple and flexible green bacteria

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Abstract

There are basic structural similarities between plant PS II and bacterial RCs of the Chloroflexaceae and Rhodospirillaceae. These RCs are referred to as PS II-type RCs. A similar relationship of PSI RC to PS II-type RCs has not been established. Although plant PSI and PS II RCs show structural and functional differences, they also share similarities. Therefore, the A and B polypeptides of PSI were searched for PSII D1 and D2 polypeptide-like sequences. An alignment without gaps was found between PSII-type D2/M helix IV and PSI B helix X, as well as a weaker alignment of PSII-type D1/L with PSI B helix X. No comparable alignment with PSI A was found. In the M/D2 alignment there were eight identities and some conservative substitutions in twenty nine residues. PSI B helix X appeared to contain a modified chlorophyll dimer and monomer binding site and a modified non-heme iron-quinone binding site. The conserved residue sequence was found only in RC polypeptides. The proposed chlorophyll dimer-monomer binding site was located transmembrane from the iron-sulfur cluster X binding site. The conserved residues generally are those that interact with prosthetic groups. Half of the conserved residues are located on the same side of the helix. Thus, although there are impediments to concluding firmly that PSI B helix X has a functional and evolutionary relatedness to the D2 PS II and bacterial M RC polypeptides, our analysis gives reasonable support to the idea.

Abbreviation: RC – reaction center

Introduction

Plant PS II RC is believed to be very similar in structure to the RC of the Rhodospirillaceae even though the three dimensional structure of plant PS II RC has not yet been achieved (Deisenhofer and Michel 1989, Hearst and Sauer 1984, Margulies 1989, Michel and Deisenhofer 1988, Trebst 1986). Sequence conservation between corresponding bacterial and PSII RC polypeptides is small – overall less than 20%. However, in specific important regions such as in transmembrane helix IV (conventionally referred to as helix D) the degree of relationship is considerably higher (Michel and Deisenhofer 1988). The PSII RCs of plants and the RCs of bacteria of the Rhodospirillaceae will be called PSII-type RCs, also referred to as ‘Q’ type (Amesz and Duysens 1986). Other reaction centers of this type are found in the Chromatiaceae (Pierson and Olson 1987) and Chloroflexaceae (Ovchinnikov et al. 1988a, Ovchinnikov et al. 1988b, Ovchinnikov et al. 1988c).
The other plant RC, PSI RC, is related in gross biochemical structure to the RCs of green sulfur bacteria of the Chlorobiaceae (Amesz and Duyssens 1986, Buchanan and Evans 1969, Hurt and Hauksa 1984, Jennings and Evans 1977, Knaff and Malkin 1976) and Helio bacterium (Mathis 1990). These will be called PS I-type RCs, and are also referred to as ‘F’ type (Amesz and Duyssens 1986). Although PS I- and PS II-type RCs have some structural and biochemical similarities, and both need to perform a similar basic function—stabilization across a membrane of a charge separation generated by light absorption—no relationship between these two RC types has been established at the molecular level (Glazer and Melis 1987, Golbeck and Bryant 1990, Malkin 1987, Margulies 1989, Rees et al. 1989). However, there is one report of attempts to align PSI RC polypeptides with PSII-type RCs (Robert and Moenne-Loccoz 1990). But, the significance of these alignments is not clear.

The RCs that have been examined appropriately (plant PS I and PS II RCs as well as RCs of the Rhodospirillaceae and Chloroflexaceae) consist of a pair of polypeptides of similar mol wt that are related but non-identical (Deisenhofer and Michel 1989, Golbeck and Bryant 1990, Glazer and Melis 1987, Malkin 1987, Margulies 1989, Ovchinnikov et al. 1988a, Ovchinnikov et al. 1988b). Important similarities and differences between PS II- and PSI-types are summarized below and in Table 1.

**Table 1. Differences and similarities between reaction centers of PSI and PS II**

<table>
<thead>
<tr>
<th>Differences</th>
<th>PS I-like</th>
<th>PS II-like</th>
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<tbody>
<tr>
<td>Reaction center polypeptides</td>
<td>2 (&gt;80 kDa)</td>
<td>2 (&lt;40 kDa)</td>
</tr>
<tr>
<td>Transmembrane segments</td>
<td>2 (11)(proposed)</td>
<td>2 (5)(determined or proposed)</td>
</tr>
<tr>
<td>Light harvesting pigments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chlorophylls</td>
<td>&gt;40</td>
<td>?8 or less</td>
</tr>
<tr>
<td>carotenoids</td>
<td>ca. 6</td>
<td>ca. 1</td>
</tr>
</tbody>
</table>

**Similarities**

Perform charge separation with similar time constants for analogous reactions (Golbeck and Bryant 1990)

**PS I**

\[ \text{P}_{700}A_0A_1 \rightarrow \text{P}_{700}A_0A_1 \rightarrow \text{P}_{700}^+A_0A_1 \rightarrow \text{P}_{700}^+A_0A_1^- \]

**PS II-type**

**Bacteria**

\[ \text{P}_{860}^+\text{BPhQ}_A \rightarrow \text{P}_{860}^+\text{BPhQ}_A \rightarrow \text{P}_{860}^+\text{BPhQ}_A \rightarrow \text{P}_{860}^+\text{BPhQ}_A^- \]

**Plants**

\[ \text{P}_{680}^+\text{PhQ}_A \rightarrow \text{P}_{680}^+\text{PhQ}_A \rightarrow \text{P}_{680}^+\text{PhQ}_A \rightarrow \text{P}_{680}^+\text{PhQ}_A^- \]

Pair of polypeptides with numerous transmembrane spans

Distinct reaction center chlorophyll

Primary acceptor a chlorophyll or chlorophyll related pigment

Secondary acceptor a quinone

Tertiary acceptor a non-heme iron

Twofold symmetry (or possible two fold symmetry)

**PS II-type.** The polypeptide pair of the RCs of purple bacteria, green-gliding bacteria, and higher plant PS II-type RC are about 32 kDa each, and contain five transmembrane segments each (Deisenhofer and Michel 1989, Ovchinnikov et al. 1988a, Ovchinnikov et al. 1988b). The Rhodospirillaceae PS II-type RC also contains four BChl (two of these BChls are in close proximity with porphyrin ring planes parallel and are termed the ‘special pair’ or ‘dimer’), a pair of BPheo, a pair of quinones, a non-heme iron and a single carotenoid molecule (Michel and Deisenhofer 1988, Michel et al. 1986, Rees et al. 1989). Plant PS II-type RC has a similar, but not necessarily identical composition (Dekker et al. 1989). A striking feature of the bacterial PS II-type RCs is the symmetry of the core structure involved in charge separation (Deisenhofer and Michel 1989, Michel et al. 1990, Trebst 1986). Because of the similarities between the RCs of...