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BRIEF COMMUNICATION

Size and power of chlorophyll *a* molecule

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Abstract

On the basis of literature and my calculations it was established that a chlorophyll (Chl) particle anchored with a phytol chain to the thylakoid membrane takes up about 1 nm^2 of the surface area. At an irradiance of 287 W m^{-2} the leaves of cabbage seedlings become saturated with photosynthetically active radiation (PAR) thus reaching the maximum photosynthetic rate of 100 μg(C) m^{-2} s^{-1}, that is 5 CO_2 molecules per 1 nm^2 per second, and the maximum power with which the Chl particle supplies the process of photosynthesis is 15 aJ.

Additional key words: *Brassica oleracea*; cabbage; irradiance; photon energy; photosynthetic rate.

The size of Chl molecule: According to Chow *et al.* (1973) the distance between particular extreme atoms of Chl *a* molecule is about 1.256 nm in one direction and 1.104 nm in another one. If the Chl molecule (without phytol) is treated as an ellipse, its surface area is about 1.08 nm^2. Because a Chl molecule is not a complete ellipse, it can be assumed that it takes *ca.* 1 nm^2 of the surface area.

Chl access to PAR: Chl molecule lies in a thylakoid lamella and is anchored to it by a phytol chain 2 nm long. If the Chl molecule takes up about 1 nm^2 of the surface area then 1 m^2 may contain not more than 10^{18} flatly arranged pigment molecules or its equivalent of variously arranged molecules. Such amount of molecules weighs about 1 mg and plants contain several hundred milligrams of Chl in 1 m^2 of the leaf. The fact that only a very small part of Chl, measured in promille, may have full access to PAR does not limit the possibility of the whole use of absorbed PAR because there is a lot of Chl in plants and each photon will find a pigment molecule.

As a result of leaf movement and chloroplast circulation in plant tissues, each time different Chl molecules are fully or partially irradiated and sun rays reach them under various gradients, and thus altogether an equivalent of 10^{18} pigment molecules have access to PAR. The main pigment absorbing PAR in higher plants is Chl *a*; the content of Chl *b* is 3–4 times lower, and the size of Chl *a* and *b* molecules is similar.

Maximum rate of photosynthesis and the power with which a Chl molecule supplies photosynthesis: Bacławska-Krzemińska (1973) found that in cabbage seedlings the maximum photosynthetic rate (P_{max}) was 100 μg(C) m^{-2} s^{-1} at the irradiance of 287 W m^{-2} (cf. Table 1). The production of 1 mol of oxygen requires in the process of photosynthesis an input of 1760 kJ. If this energy is divided by the Avogadro number, then 2.92 aJ fall to one molecule of the produced oxygen.

The energy necessary for the assimilation of one atom of carbon is near to the above 3 aJ, and thus the P_{max} of 100 μg(C) m^{-2} s^{-1} corresponds to 5×10^{18} molecules of CO_2 per m^2 and s, and requires the power of 15×10^{18} aW m^{-2}. Such amount of energy is supplied by not more than 10^{18} irradiated Chl molecules which are contained in 1 m^2. On the average, 15 aW fall to one molecule Chl. It is the maximum power with which the Chl molecule transfers energy for photosynthesis at the irradiance of 287 W m^{-2}.

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The use of solar irradiance by Chl: The main absorption spectra of Chl *a* according to Zscheile *et al.* (1941) are 440-460 nm wide in the blue radiation and 660-680 nm in the red one which makes up about 6 % PAR. More exactly, the PAR utilization by Chl can be estimated on the basis of sun irradiance measured at 10 nm intervals (Table 2). The calculations were based on the solar constant of 1353 W m^{-2}. Solar irradiance which caused the P_{max} in cabbage leaves (287 W m^{-2}) was 0.21 of the solar constant. Let us assume that with a 5 fold lower irradiance the spectral irradiance is also 5 fold lower. In Table 2, the *C* column is the result of multiplaying column *B* by 0.21. Thus the solar irradiance corresponds exactly to the power with which the Chl molecule supplies photosynthesis.

Table 1. The dependence of photosynthetic rate on irradiance.

	Irradiance [W m^{-2}] 36	72	108	144	216	287	360
Photosynthetic rate [μg(C) m^{-2} s^{-1}]	13	29	46	61	76	100	100
Power demand [W m^{-2}]	1.95	4.35	6.90	9.10	11.40	15.00	15.00
PAR use [%]	5.4	6.0	6.4	6.3	5.3	5.2	4.9

Table 2. The power emitted by the sun in the blue and red radiation absorbed by chlorophyll at the total irradiance of 1352 W m^{-2} in the investigations by Shul'gin (1973) and 287 W m^{-2} in the investigations by Bacławska-Krzemińska (1973).

A Wavelength [nm]	*B* Irradiance acc. to Shul'gin [W m^{-2}]	*C* Irradiance acc. to Bacławska (B×0.21) [W m^{-2}]	*D* Mean photon energy [aJ]	*E* Number of photons per 1 nm^2 and s acc. to Bacławska
430–440	18.10	3.80	0.457	8
440–450	21.10	4.43	0.447	10
640–650	16.61	3.49	0.309	11
650–660	16.38	3.44	0.304	11
Total	72.19	15.16		40

Conclusion: A Chl molecule passes all the energy received from the sun to the photosynthetic system in a reaction centre (RC). Thus the maximum power of a Chl molecule is not a specific trait of that pigment but the power with which the sun supplies a Chl *a* molecule with blue and red radiation photons when the photosynthetic system is saturated with PAR.

The absorption of PAR by Chl and the transport of electrons from one molecule to another takes part very quickly, in about 0.1-0.2 ps (van Grondelle *et al.* 1994) whereas the dark reactions lasting 10-14 ms (Myers and Graham 1971) limit the P_{max} and thus mark the value of irradiance at which the photosynthetic system is PAR-saturated. With strong, saturating irradiance, P_{max} depends on the rate of metabolic processes in RC. At midday, in natural conditions of vegetation, plants often reach PAR saturation.

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