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Photosynthesis in Polarized Light

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1. INTRODUCTION

The effect of polarized light on plant organisms is as yet little known. The opinions on the subject are controversial and some reports mention a peculiar biological effect of polarised light, while other results published deny any such activity. Several investigations have been undertaken on the influence exerted by polarized light on photosynthesis (Dastur and Asana 1932, Dastur and Gunjikar 1934, Johnston 1937) but the results obtained are ambiguous. There are two main obstacles in any researches on the effect polarized light has on photosynthesis. First, it is very difficult to obtain polarized light of sufficient intensity and falling on a sufficiently large area. When this is surpassed the polarized light beam is strongly depolarized by the many reflections and refractions on the inside leaf surfaces which makes very difficult any accurate estimation of the polarization degree.

The micromethod of photosynthesis measurements elaborated by the writer eliminates to a great extent the main difficulties just mentioned. With this method it is sufficient to illuminate a one centimetre square which is easy when a Nikol prism is used. Moreover, by experimenting with leaves of water plants which have few or even one cell layers only conditions are created in which light depolarization is reduced to minimum.

It was the aim of this work to investigate the influence of polarized light on photosynthesis rate in *Lemna trisulca* leaves. In experiments both linear and circular light polarization was applied.

2. MATERIAL AND METHODS

For experiments young leaves of *Lemna trisulca* L. were used. The surface area of the leaves was 4—8 mm² each and they were prepared in the usual manner. A detailed account on the method of photosynthesis measurements was published in an earlier paper (Zurzycki 1954).

A 1000 W projection lamp working on a 215 V current supply was used as the light source. The light was directed through a 10 cm liquid filter containing a water solution of ferrous ammonium sulphate (70 g/1) and reflected by the microscope mirror to the special, polarizing or neutral filters placed just under the respirometer chambers. Light polarization was obtained with a Nikol prism. For control measurements the prism was replaced by a neutral filter made of photographic plate (Film Polski diapositive plate), suitable blackened and mounted exactly like the Nikol prism. Transparency curves for the Nikol and the neutral filter plotted from measurements with a Pulfrich photometer are given in Fig. 1. These curves show that transparency within the visible radiation range is very similar for both filtres.

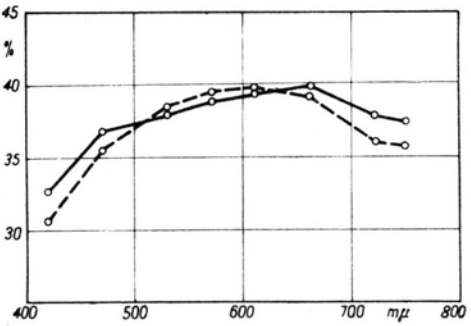

Fig. 1. Curve of spectral transparency in the neutral filter and the Nikol prism measured in a Pulfrich photometer. Transparency measured in %. —o— neutral filter, — — o — — Nikol.

To compare the absolute intensities of light transmitted by each of the two filters measurements were made with a Zeiss vacuum thermo-couple. The results obtained (table 1) indicated that the Nikol transmitted light energy in quantities smaller by approximately 5% that the neutral filter.

When this result is compared with the spectral absorption curve it seems that the higher energy transmitted through the neutral filter is mainly due to long wave radiation predominant in the projection lamp spectrum.

Table 1
Intensities of light transmitted by Nikol and by neutral filter as measured by vacuum thermo-couple

No	Nikol Galvanometer scale units	Filter Galvanometer scale units	Nikol in %
1	63	67	94,0
2	55,5	59,5	93,3
3	58,5	62,5	93,6
4	63	67	94,0
5	58	60	96,7
6	65	68	95,6
		Average	94,53±0,54

To obtain circular polarisation 1/4 λ mica plates were placed in the necessary position on the nikol. For control experiments the same plates were placed on the neutral filter. The mica plates were adjusted for sodium light and consequently for other wave lengths the resultant polarization was more or less elliptical.

3. RESULTS

A. *Linear polarization*

In the first series of experiments weak light was used, and its intensity after passing through the Nikol was about 200 lux. At this light intensity photosynthesis rate was low, usually just above the compensation point. For the first 20—40 minutes the plant leaf was illuminated with unpolarised light, then the neutral filter was replaced by the Nikol and illumination in the new conditions continued for the next 30—60 mins, when once again unpolarized light was applied. In this manner it was possible to relate the photosynthesis rate in polarized light to the mean rate in unpolarized light before and after the Nikol was installed. The normal measurement results are demonstrated by the curves 1 and 2 on Fig. 2. Photosynthesis rate in polarized light was often the same as in normal light. However in some cases a perceptible drop in photosynthesis rate was noted in polarized light in other rare instances a slight stimulation effect of polarized light was also observed. On the other hand photosynthesis rate varied sometimes in normal light before and after illumination with polarized light and therefore no definite meaning could be attached to these changes in the rate. Such changes probably resulted from

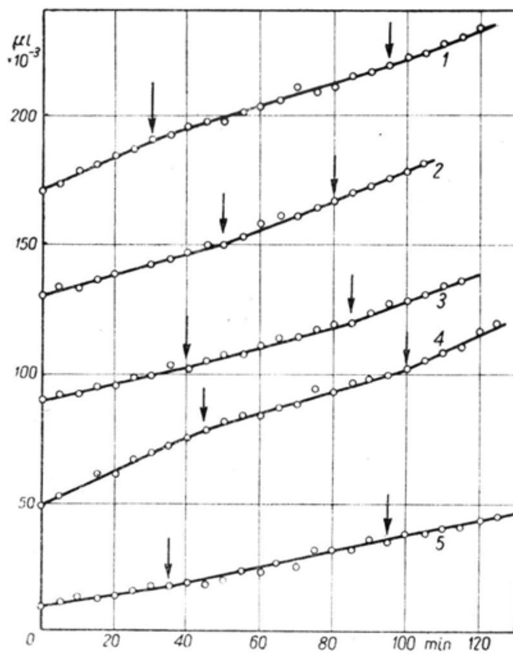

Fig. 2. Assimilation in light polarized linearly — curves 1 and 2, and circularly — curves 3—5 at light intensity approximately 200 lux. Abscissae — time in mins, ordinates — oxygen production in μl 10^{-3}. Arrows indicate the change in the kind of light.

Table 2
Photosynthesis in plane polarized light
(Arbitrary units)

No of exp.	Respiration	Apparent photosynthesis			Photosynthesis in pol. light in %
		ord. light	pol. light	ord. light	
2	—7,4	+12,8	+10,2	+9,4	95,1
3	—6,25	+ 6,93	+ 5,85	+7,76	89,0
5	—3,67	+ 1,85	+ 1,60	+1,77	96,1
8	— 4,50	+ 1,56	+ 1,80	+1,80	101,9
				Average	95,52±2,64

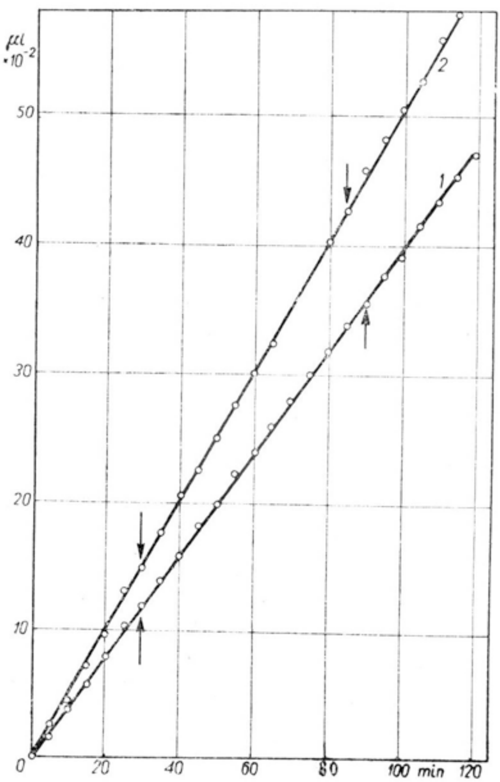

Fig. 3. Assimilation in light polarized linearly — curve 1, and circularly — curve 2 at light intensity approximately 2000 lux. Abscissae — time in mins, ordinates — oxygen production in μl 10^{-2}. Arrows indicate the change in the kind of light.

very small unnoticeable differences in the installation of filters when they were exchanged and the consequent slight differences in light intensity to which the plants responded. To eliminate these accidental errors mean values of the observed photosynthesis rate (taking into account the respiration rate) in polarized light were refered to the mean rate of photosynthesis in normal light. The so computed results are given in Table 2. The mean photosynthesis rate in polarized light computed from 4 repetitions was 95,52 ± 2,64% of the photosynthesis rate measured in normal light.

If it is considered that this result tallies with the relative light transparency of the Nikol in respect to the transparency of the neutral filter and that in weak light the photosynthesis rate is directly proportional to light intensity it becomes evident that light polarized linearly has the same effect on photosynthesis as unpolarized light of the same intensity.

In strong light of 2000 lux the assimilation rate is exactly the same in polarized light as it is in normal light (Fig. 3 curve 1).

B. *Circular polarization*

The results from corresponding experiments on circular light polarization are illustrated by the curves 3—5 on Fig. 2 and by Tables 3 and 4. Similarly as in the case of linear polarization also in circularly polarized light photosynthesis was usually somewhat inhibited and rarely stimulated. Relatively to normal light the photosynthesis rate for dextro- and laevorotatory light respectively, calculated in mean values, was 97,81 ± 3,33% and 97,53 ± 1,87% of photosynthesis rate in unpolarised light.

Table 3
Photosynthesis in circular left rotating polarized light
(Arbitrary units)

No of exp.	Respiration	Relative photosynthesis			Photosynthesis in pol. light in %
		ord. light	pol. light	ord. light	
4	—3,1	+3,5	+2,4	+2,1	93,2
6	—5,3	+0,7	+1,43	+0,4	115,0
7	—7,7	—1,7	—1,6	—2,2	106,0
9	—7,6	—2,2	—2,7	—3,0	98,0
10	—4,5	+2,45	+1,1	+1,37	87,4
11	—4,5	+1,37	+1,35	+1,80	96,1
12	—6,9	+6,75	+4,8	+6,4	86,8
13	—4,35	—2,2	—2,0	—1,8	100,0
				Average	97,81±3,33

Table 4
Photosynthesis in circular right rotating polarized light
(Arbitrary units)

No of exp.	Respiration	Apparent photosynthesis			Photosynthesis in pol. light in %
		ord. light	pol. light	ord. light	
14	—4,35	—1,8	—1,7	—1,6	100,0
15	—3,3	+8,0	+6,5	+6,7	92,0
16	—3,3	+3,87	+3,75	+3,85	98,5
17	—3,3	+3,85	+3,5	+3,2	99,6
				Average	97.53±1,87

These differences corresponded within error limits to the differences in transparency of the two filters and indicated that independently of the rotation direction, also circularly polarized light acted on photosynthesis in the same way as unpolarized light of the same intensity.

In circularly polarized strong light photosynthesis rate was exactly of the same value as in unpolarized light of like intensity (Fig. 3 curve 2).

4. DISCUSSION

For a long time the biological effect of polarized light did not focuse the attention of research workers. First mention of the problem was made in 1923 when Semmens reported that moonlight quickened seed germination and attributed this effect to the partial polarization of moonlight. In 1924 and 1925 Baly and Semmens for the first time demonstrated experimentally the peculiar effect exerted by polarized light on starch hydrolysis. In later, more detailled experiments (1930—1947) Semmens demonstrated that starch accumulated in leaves in normal light was quickly decomposed in polarized light. When the incident light was of sufficiently high intensity the disintegration produced a sudden increase in the sugar level and consequently the increase of osmotic pressure burst the cells (Semmens 1934, 1947). Moreover, a faible response of starch to polarized light was observed by Semmens in vitro even when the enzymes were absent.

However, the hydrolytic effect of polarized light on starch in vitro was denied by numerous workers. Jones (1923), Bunker and Anderson (1928), and Noves Albert and Rubenstein (1928) did not obtain results corroborating those reported by Semmens.

Macht and coworkers (1925) ivestigated the effect exerted by polarized light on the activity of some ferments and pharmacologically active bodies, and found that in all instances such an effect existed. It was also reported that polarized light was active in the case of microorganisms (Macht and Hill 1925, Bhatnager and Lal 1926, Lal and Mathur (1926). Macht (1926) observed a quickened seedlings growth in polarized light, though, in this case the differences were not considerable and might have been due to inacurate technique (Dastur and Asana 1932). In 1934 Castle reports that in *Phycomyces* the phototropic reaction is the same in polarized as in normal light. Somewhat later Johnston (1937) confirms this on phototropic reactions in *Avena* coleoptiles. In contradiction to these experiments of short duration, Semmens (1930) found that longlasting polarized light illumination was harmful to plants.

The influence of linearly polarized light on photosynthesis was investigated for the first time by Dastur and Asana (1932). They worked with light polarized in 80 — 90% finding no drop in the starch level and insignificant differences, remaining within error limits, between the general increase of carbohydrates in polarized and normal light. Johnston (1937) using a sensitive spectrographic method observed no difference in the CO_2 assimilation rates regardless of the kind of light.

On the other hand Dastur and Gunjikar (1934) observed that in the case of elliptical polarization the carbohydrate synthesis varied distinctly from that in normal light of the same intensity, the former having a lower rate. Although the statistical test gave significant results the data reported by the two workers scattered and in some cases photosynthesis rate in elliptically polarized light was higher than in normal light.

In this work two light intensities were experimented with: 1) weak light very near the compensation point where possible differences in absorption might influence distinctly assimilation and 2) strong light where, according to S e m m e n s, the starch hydrolysis might also affect photosynthesis.

The results obtained indicate that in weak light the statistical difference between photosynthesis rates in polarized and normal light corresponds exactly to the difference in the intensity of the light used. It follows that polarized and normal light are in their effect exactly alike. In strong light there are absolutely no differences in assimilation rate. At this high intensity the slight differences in light absorption have absolutely no influence on assimilation rate (cf. Z u r z y c k i 1954).

R a b i n o w i t c h (1951) believes that for various polarization degrees chloroplast anisotropy may cause differences in light absorption. The chloroplasts are anisotropic only in the profile position but this position may be induced with strong light when the possible differences in absorption have no effect on photosynthesis (Z u r z y c k i 1954), while the characteristic chloroplast arrangement in weak light is the flat position when the chloroplasts are optically isotropic. It is therefore plausible to expect that differences in polarized light absorption will appear solely when two conditions are fulfiled: the light must be weak and the chloroplast must be in the profile position. In weak light such an arrangement is temporary and lasts 15—20 mins which is not long enough to measure the rate of photosynthesis with the technique of this work.

In strong light no differences of assimilation rate in polarized and normal light were observed. It seems to appear from the data obtained by S e m m e n s that for the light intensity and illumination time used in this work starch decomposition is not very rapid. Thus, it is possible that a stronger and longlasting irradiation with polarized light will influence the assimilation rate, though, such an effect would be secondary and a result of an increase in the sugar concentration within the cell.

Finally, also circular light polarization has no peculiar influence on photosynthesis. The lack of any difference between laevo-and dextrorotatory light polarization indicates that there is no circular dichroism. To improve on the present data on circular light polarization further experiments should be carried out with monochromatic light.

5. SUMMARY

With the method worked out earlier by the writer photosynthesis of *Lemna trisulca* leaves was investigated in linearly and circularly polarized light. In light of low intensity (200 lux) equally as in light of higher intensity (2000 lux) both the linear and circular light polarizations have the same effect on photosynthesis as normal light of the same intensity. In circularly polarized light no differences was observed between the dextro- and laevorotatory light effect.

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STRESZCZENIE

Za pomocą metody opracowanej poprzednio przez autora badano fotosyntezę liści *Lemna trisulca* w świetle spolaryzowanym liniowo i kołowo. Zarówno w słabej intensywności światła (200 luksów), jak i w silnej (2000 luksów), fotosynteza przebiega w świetle spolaryzowanym liniowo i kołowo, identycznie jak w świetle zwykłym tej samej intensywności. Przy zastosowaniu światła kołowo spolaryzowanego nie stwierdzono istotnych różnic między działaniem światła o prawym względnie lewym kierunku rotacji.

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