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Characteristic of vegetative and resting forms of *Wolffia arrhiza* (L.) Wimm.

I. Growth and dynamics of their mutual transformations

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INTRODUCTION

The genus *Wolffia (Lemnaceae)* comprises the smallest and simplest flowering plants. They develop on the surface of stagnant waters, are deprived of roots and conductive tissues, and are remarkably small in size; e.g. for *Wolffia arrhiza* the dimensions are about 1.2 mm length and 0.4 mm breadth. Individual members are spheric or ellipsoidal, sometimes flattened at the top; very often two members are connected with each other. They flower rarely (D a u b s 1965) but propagate rapidly in a vegetative way. In the basal part of the parental member there is a funnel shaped pocket from which secondary fronds grow out.

Species of the *Lemnaceae* can be easily grown in controlled laboratory conditions and often they constitute excellent experimental objects. Species of the genus *Wolffia*, however, were seldom used because of their small dimensions, which are on the border line between macro- and microscopic observation possibilities. Numerous observations on *Wolffia arrhiza* have shown that this genus produces two forms of vegetative fronds: a) floating on the surface of the water reservoir, b) immersed, falling down to its bottom. These two kinds of fronds differ by their requirements with reference to the composition of the nutrient solution, by growth dynamics, size, fresh and dry weight, specific density, starch and chlorophyll content (paper on these topics in print).

Vegetative fronds which fall down to the bottom have been hitherto described as turions (H e g e l m e i e r 1868; L a n d o l t 1957). The difference in size between the two forms of vegetative fronds is insignificant. In favourable growth conditions both form are able to grow rapidly and to form secondary fronds. According to L a n d o l t (1957) turions of *Wolffia arrhiza* are externally almost indiscernible from vegetative fronds and show a reduced ability to form new turions. Observations however made in this laboratory have shown that true turions are much smaller than vegetative fronds; their dry weight and specific density are higher, besides they do not form secondary fronds. They appear in unfavourable growth conditions, e.g., in older cultures after the exhaustion of the mineral compounds in the nutrient solution. Normally they drop to the bottom, but after transfer to a fresh nutrient medium they germinate and come out to its surface.

Considering the discrepancies between the above observations and the data quoted in literature it seemend appropriate to undertake a detailed study on the developmental forms of *Wolffia arrhiza* and to analyse them with regard to morphology, anatomy, physiology, and biochemistry.

It is shown in the present study that three developmental forms are characteristic of *Wolffia arrhiza*, viz. two vegetative forms (floating and immersed fronds) and turions. The life cycle of these forms, their growth dynamics, their mutual relationships and transformations made the object of detailed investigations. They include also the action of some external factors (light intensity, darkness) on these transformations.

MATERIAL AND METHODS

Fronds of *Wolffia arrhiza* were collected in 1956 from water basins in the region of Kierskie lake near Poznań. A sterile culture was obtained by Czopek (1959a). The stock culture of *Wolffia arrhiza* was allowed to grow in a light thermostat (about 1800 lux, 26—28°C). Transfers were performed every 4 weeks onto Pirson's and Seidel's nutrient solution with addition of sucrose (Kandeler 1955). In our study we used Erlenmeier flasks of 200 ml capacity containing 50 ml of the said solution with or without addition of sucrose. Cultures on small surfaces were allowed to grow in test tubes (1 cm diameter) on 20 ml solution. After sterilisation (1 atm., temp. 120°C., 45 min.) about 10 vegetative fronds or turions were transferred under sterile conditions into flasks or test tubes by means of a special loop.

Results of experiments on the influence of the numerical ratio of floating and immersed fronds on the dynamics of their growth proved that the initial ratio of the two forms 1 : 1 is the most favourable for growth of the cultures. For this reason cultures used in our study on the action of light intensity consisted initially of 5 floating and 5 immersed fronds. The cultures were allowed to grow in continuous light in a light thermostat. The intensity of light emitted by fluorescent tubes and measured on the surface level of the solutions was 1800 lux. In experiments on the action of the light intensity on growth the cultures were exposed to light of 500 and 5300 lux intensity. Besides controls were allowed to develop in darkness in constant thermal conditions. The temperature was maintened on the level 26—28°C.

Evaluation of the results was performed by counting the number of vegetative fronds in each flask every 4 days (up to the 20th days) and by calculating mean values for the whole series of cultures consisting each of 20—30 flasks.

Basing on the previously observed (Czopek 1959a, and preliminary investigations) exponential growth of the number of fronds with time a coefficient of daily growth K has been calculated according to the formula:

$$\frac{dN}{dt} = \mathrm{K} \cdot \mathrm{N} \text{ hence } ln\frac{N}{N_0} = K \cdot t \text{ or } N = N_0\, e^{Kt}$$

where N is the number of fronds at the moment t; N_0 is the initial number of fronds (at the moment $t = t_0 = 0$). In the following coefficient K is considered the best measure of the rate of daily growth of a given culture.

Each series was made in three replications.

Turions appear irregularly after a longer growth period; they are smaller in size than vegetative fronds and they appear suddenly in great number. The exact number, however, was not established.

RESULTS

As it has been mentioned in the introduction — besides turions (fig. 1c) — two forms of vegetative fronds of *Wolffia arrhiza* have been distinghuished: viz. the floating (fig. 1a) and the immersed fronds (fig. 1b). A detailed characterisation of their morphological, anatomical, biochemical and physiological features will be given in the second part of the present paper (in print). The present work refers to kinetics of formation and growth of the just mentioned three forms of *Wolffia arrhiza*.

1. *Vegetative fronds floating on the water surface*

On a mineral nutrient solution without sucrose floating fronds develop well, though slightly weaker than on a nutrient medium with sucrose (fig. 2); $K = 0.183$. The fronds remain alive for at least 20 days. Neither their dropping to the bottom, nor transformations into other vegetative forms — immersed fronds — were observed.

Mineral nutrient solutions with addition of 1% sucrose (fig. 2) proved to be a very favourable medium for the development of vegetative fronds of *Wolffia arrhiza*. Floating fronds demonstrate a more rapid growth ($K = 0.204$) and are slightly smaller than those grown on a nutrient solution without sucrose, but their fresh and dry weight are slightly

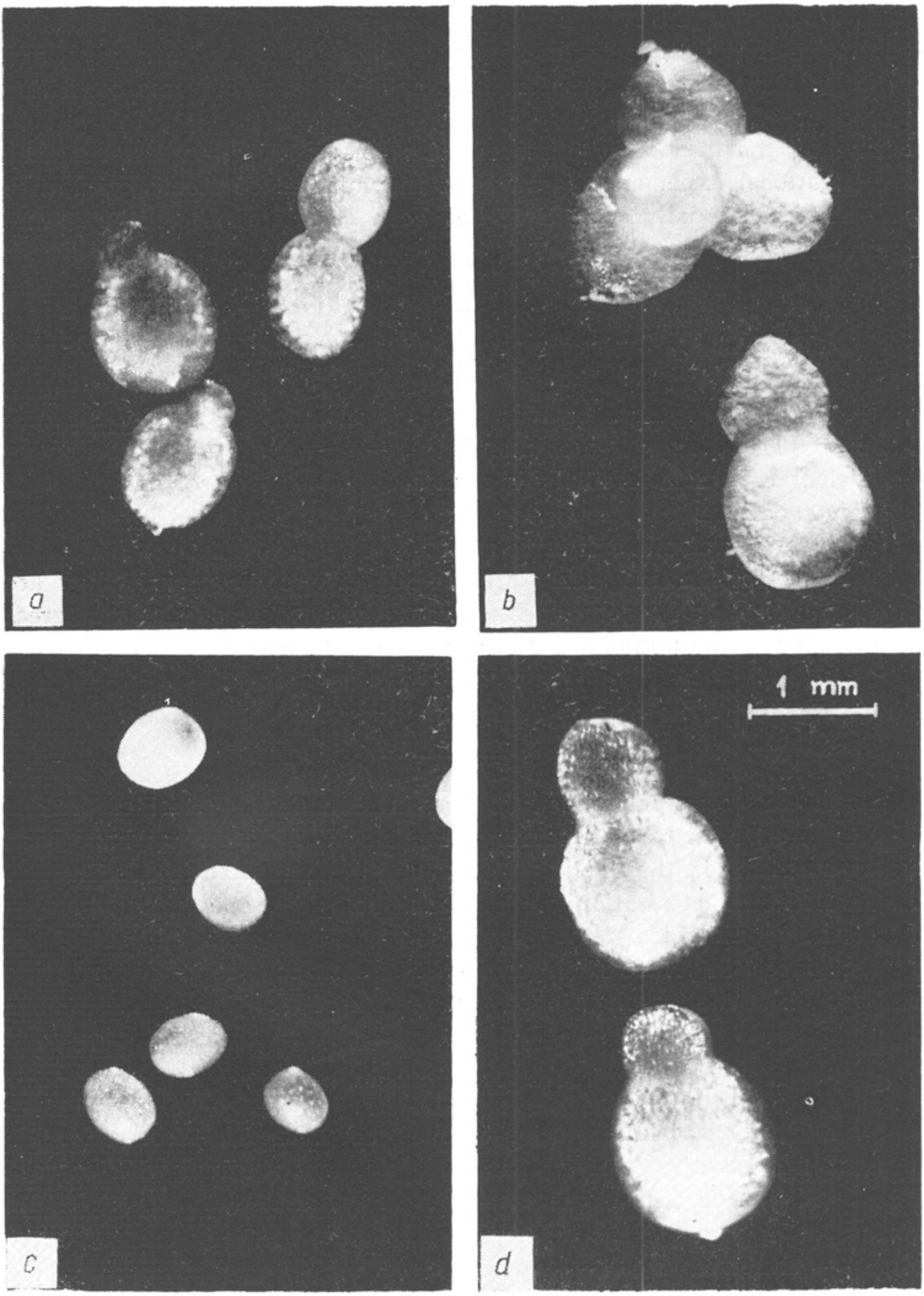

Fig. 1. Vegetative fronds and turions of *Wolffia arrhiza* (cultured on nutrient solution with sucrose, in light intensity 1800 lux, 1*d* excepted)

a — floating vegetative fronds, *b* — immersed vegetative fronds, *c* — turions, *d* — floating vegetative fronds cultured in light intensity 5300 lux without sucrose

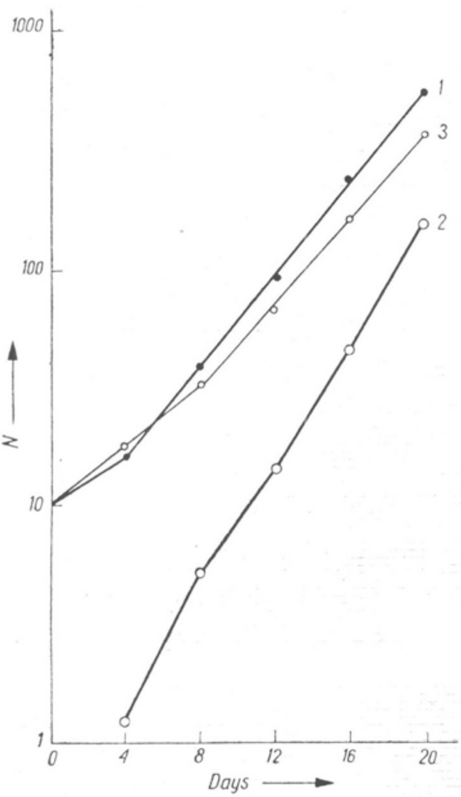

Fig. 2

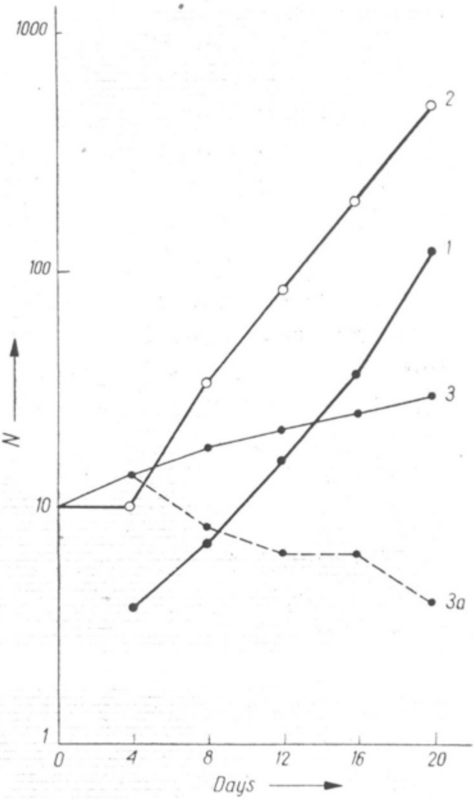

Fig. 3

Fig. 2. Rate of growth of floating vegetative fronds

1 — 1% sucrose, floating vegetative fronds; *2* — 1% sucrose, immersed vegetative fronds; *3* — without sucrose, floating fronds

Abscissae — days of culture; ordinates — the number N of vegetative fronds in logarythmic scale

Fig. 3. Rate of growth of immersed vegetative fronds

1 — 1% sucrose, floating fronds, *2* — 1% sucrose, immersed fronds, *3* — without sucrose, immersed fronds, *3a* — without sucrose, immersed living fronds

Abscissae and ordinates as in fig. 2.

higher. The formation of immersed fronds was observed to occur already in the first days. They manifested a much better growth than those which developed in similar conditions from a culture containing initially only immersed fronds; they remained alive till the end of the experiment (20 days). In this connection there arises a question whether the observed considerable increase of frond number is ascribable solely to an intensive growth of immersed fronds or is the result of a continuous transformation of floating fronds into immersed ones. The last alternative is spoken for by a greater increase of immersed fronds in a culture derived from floating fronds (at the moment $t = 0$) than from immersed fronds; and by a relatively small difference in the growth rate shown by floating fronds developing on a mineral solution ($K = 0.183$), and on a nutrient solution with sucrose ($K = 0.204$). In order to give a decisive answer to this question experiments were performed consisting in the daily elimination of newly formed immersed fronds from cultures grown in nutrient solution + sucrose. A transformation of floating fronds into immersed fronds proved to proceed continuously during the 20 days of the experiment. The mean daily number of floating fronds transformed into immersed ones increased from 0.62 to 2.4. After 20 days the immersed fronds resulting from the transformation of floating fronds constitute about 12.5% of their total number.

2. *Immersed vegetative fronds*

The growth in number of immersed fronds inoculated to a nutrient solution without sucrose is much weaker ($K = 0.055$) in comparison with the growth of the same fronds on a nutrient solution with sucrose (fig. 3). It was found that a great number of these fronds dies during the growth period. It was also observed that in a culture of immersed fronds a small number of floating vegetative fronds always appeared. These fronds were eliminated every day in order to test whether there is an uninterrupted transformation of immersed fronds into floating ones. It was found that very few immersed fronds occasionally rise to the water surface and form floating fronds.

Immersed vegetative fronds cultured on a nutrient solution with sucrose behaved in a different way. They multiplicate intensively and remain alive till the end of growth (20 days). Floating fronds appeared only sporadically as in the cultures without sucrose ($K = 0.07$). The subsequent development of these fronds does not differ from the development of normal floating fronds and is determined by the growth conditions.

3. *Influence of the initial ratio of floating and immersed vegetative fronds on the dynamics of their growth*

It was already mentioned that the initial ratio of floating and immersed fronds is not without effect on the subsequent development of the colony. In order to obtain more information on this point experiments were carried out with fronds of *Wolffia arrhiza* allowed to grow on nutrient solutions without sucrose and with the addition of this sugar

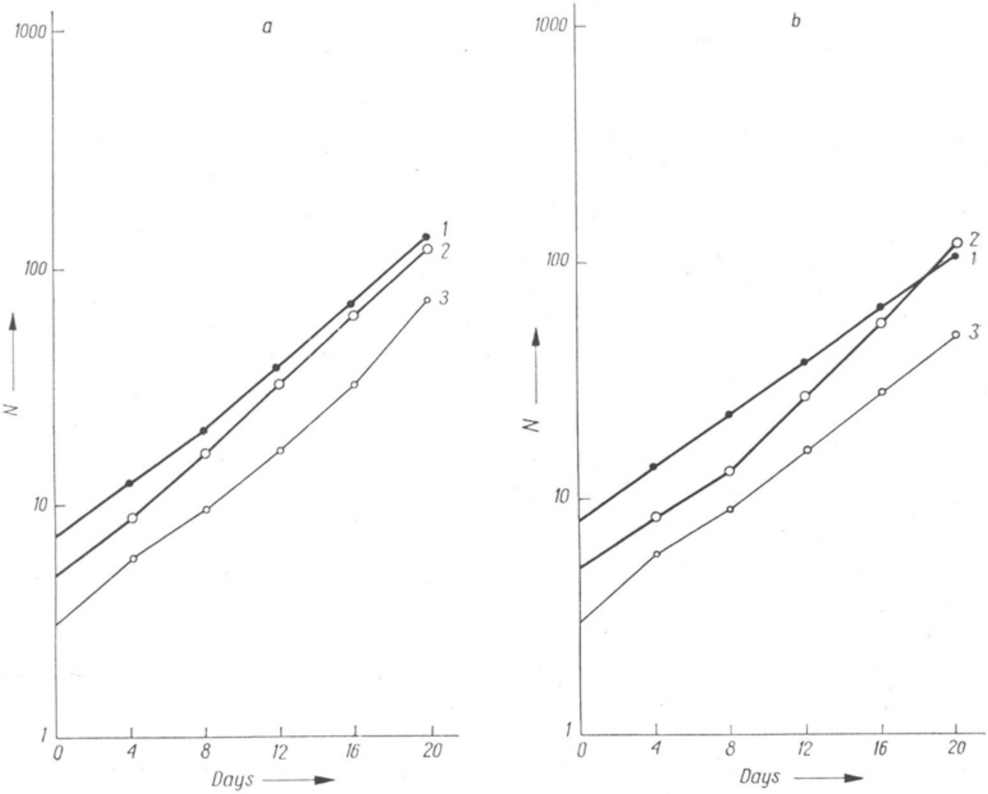

Fig. 4. Rate of growth of floating vegetative fronds in dependence on various initial ratios (R) of floating to immersed vegetative fronds

fig. 4a — Nutrient solution without sucrose
1 — $R = 3:1$; 2 — $R = 1:1$; 3 — $R = 1:3$
Abscissae and ordinates as in fig. 2.

fig. 4b — Nutrient solution with 1% sucrose
Denotation as in fig. 4a

(1%) in 3 modifications of the ratio R of floating to immersed fronds, viz. 1 : 1, 1 : 3 and 3 : 1 (fig. 4 and 5).

Independently of the presence of sucrose in the nutrient solutions optimum growth of immersed vegetative fronds was observed for the initial ratio $R = 1:1$. On nutrient solution without sucrose the number of immersed living fronds — after an small initial decrease of their number — increases constantly till the end of the experiment. In the two other modifications the growth was weaker and many dead fronds were found. For floating fronds the ratio 1 : 1 also appeared to be the most favourable and independent of the composition of the nutrient solution. Weakest growth was observed in cultures for which $R = 3:1$.

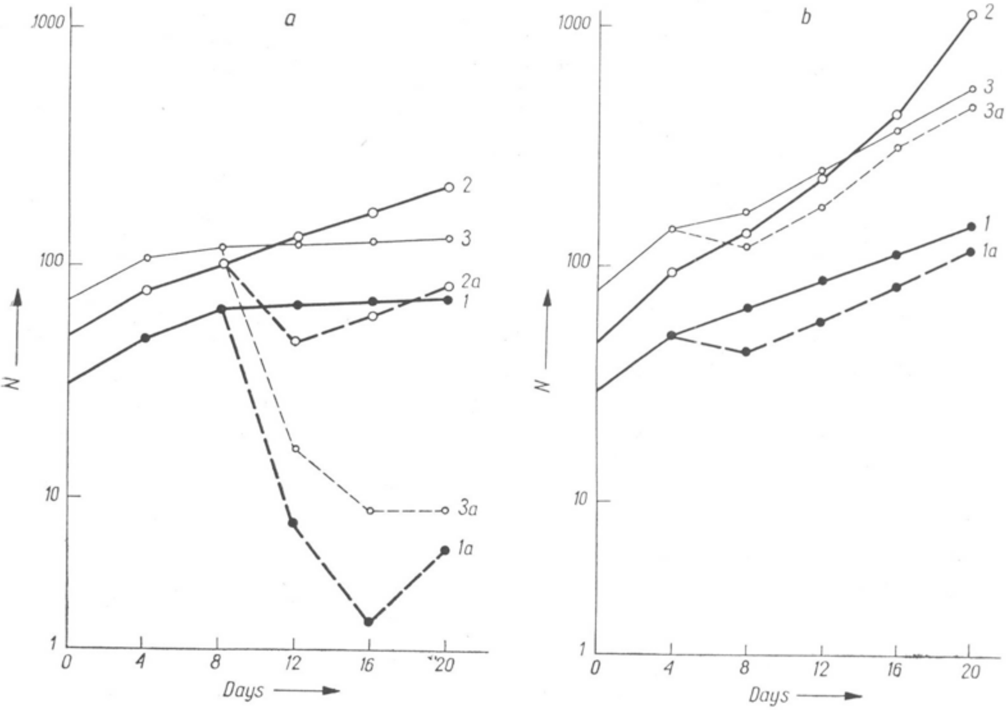

Fig. 5. Rate of growth of immersed fronds in dependence on various initial ratios (R) of floating to immersed vegetative fronds

fig. 5a — Nutrient solution without sucrose
Denotation as in fig. 4a; 1a, 2a and 3a — number of immersed living vegetative fronds present in the total number of fronds denoted by 1, 2, 3 respectively

fig. 5b — Nutrient solution with 1% sucrose. Denotation like in fig. 4a and 5a

4. *Influence of the ligth intensity on the growth of vegetative fronds of Wolffia arrhiza*

It results from our experiments that the presence of sucrose in the nutrient solutions stimulates the formation and the growth of immersed vegetative fronds. The more favourable trophic conditions are (probably) a decisive factor. In this connection it was considered appropriate to examine whether the factors increasing the photosynthetic activity of the fronds have a similar effect. With this aim in view colonies of *Wolffia arrhiza* were grown on both kinds of nutrient solutions in light intensities 500 and 5300 lux; the initial ratio R was the optimum ratio 1 : 1. Results are shown in fig. 6. In all cases the growth of immersed vegetative fronds proceeds in a similar way as in ligth of 1800 lux intensity (comp. fig. 3). The rate of growth, however, of floating fronds in 500 lux light intensity is feeble ($K = 0.099$ in a nutrient solution with

Table I. Values of growth coefficients K of vegetative fronds of *Wolffia arrhiza* in dependence on the kind of nutrient solution and light intensity

Light intensity		Darkness	500 lux	1800 lux	5300 lux
Mineral nutrient solution	Floating vegetative fronds	0,004	0,113	0,183	0,234
	Immersed vegetative fronds	0,005	0,058	0,055	0,085
Mineral nutrient solution + 1% sucrose	Floating vegetative fronds	0,024	0,099	0,204	0,183
	Immersed vegetative fronds	0,032	0,151	0,200	0,162

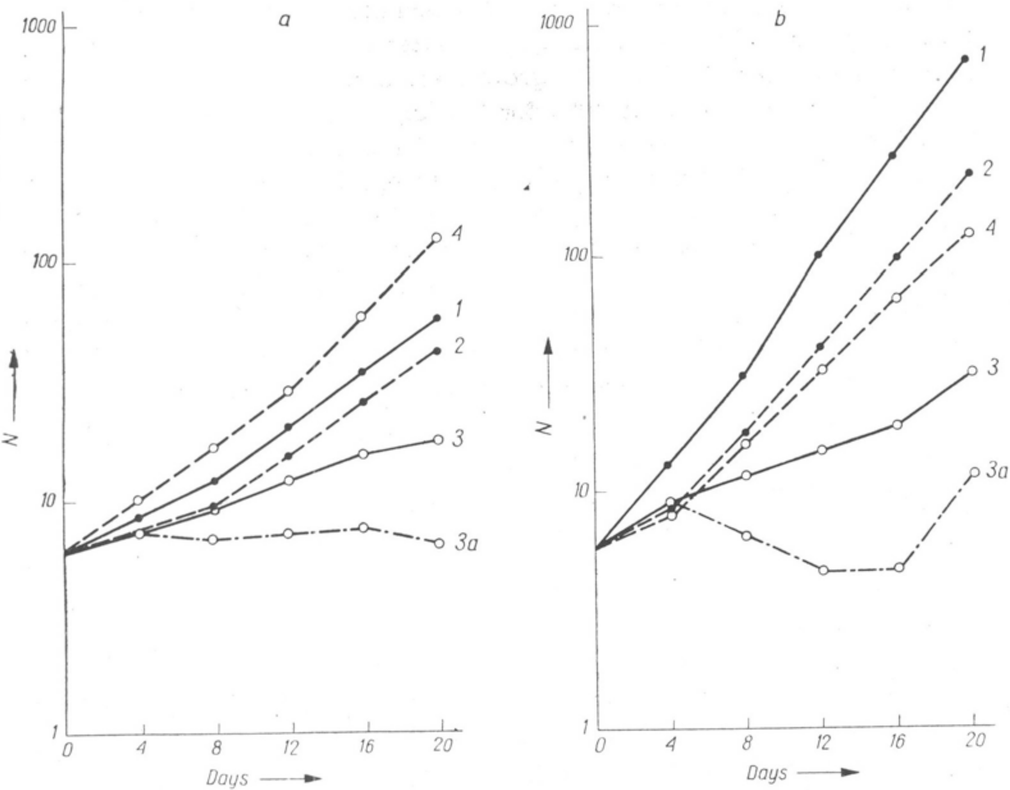

Fig. 6. Influence of various light intensities on growth rate of vegetative fronds of *Wolffia arrhiza*

fig. 6a — Light intensity 500 lux; 1 — floating fronds on nutrient solution without sucrose, 2 — floating fronds on nutrient solution with 1% sucrose, 3 — immersed fronds on nutrient solution without sucrose, 3a — immersed living fronds on nutrient solution without sucrose, 4 — immersed fronds on nutrient solution with 1% sucrose. Abscissae and ordinates as in fig. 2.

fig. 6b — Light intensity 5300 lux. Denotation like in fig. 6a.

sucrose). On the other hand, in strong light (5300 lux) floating fronds manifest an intensive growth, especially on nutrient solutions without sucrose ($K = 0.234$). The dimensions, fresh and dry weights of one frond, are even somewhat higher than those of an immersed frond from optimum culture conditions (fig. 1d).

5. *Growth of vegetative fronds of Wolffia arrhiza in darkness*

The fact that *Wolffia arrhiza* is able to utilise sucrose induced us to make a study on the development of this species in darkness.

The experiments are carried out with fronds of *Wolffia arrhiza* growing in a dark thermostat on nutrient solutions with or without sucrose. Every 4 days up to the 32-nd day, part of flasks was removed, the percentage of frond increase was calculated and observations were made on their ability to further growth after transfer to light (1800 lux). In darkness after 32 days the growth on a nutrient solution without sucrose amounted to about 10% for floating and immersed fronds whereas during the same period about 80% of immersed fronds and 20% of floating ones perished. Immersed fronds kept in darkness for 16 days undertake growth again when transferred to light and after 8 days of illumination their number increases by 52%; however, after a longer period spent in darknes this percentage drops markedly. Floating fronds, on the other hand, kept in darkness for 20 days, double their number within 8 days after transfer into light. However, a prolonged period of darkness considerably decreases the percentage of fronds able to growth after transfer to light.

Wolffia arrhiza allowed to grow for 32 days on nutrient solutions with sucrose and transferred to darkness immediately after inoculation shows a high percentage of fronds undertaking growth, viz. 98 and 70% for immersed and floating fronds respectively. In cultures kept in light for the first 8 days following inoculation and subsequently transferred into darkness this percentage was reduced to 6 and 27% respectively (after 32 days spent in darkness). This phenomenon was not recorded on nutrient solutions without sucrose. Inoculation (i.e. transfer) on a fresh nutrient solution acts like an impulse inducing intensive growth. Cultures kept in darkness for 20 days undertake intensive growth when transferred into light and after 8 days the number of immersed and floating vegetative fronds increases by about 10 and 4 times recpectively; a longer period of darkness, however, inhibits considerably the start in light.

Summing up the experimental results it can be stated that immersed fronds — on nutrient solution with sucrose — are more stabile and react much weaker to changes of external factors; whereas, floating fronds are much more sensitive; besides their growth depends on photosynthesis.

6. *Influence of the degree the nutrient solution surface is covered with floating vegetative fronds upon the formation of immersed vegetative fronds*

Cultures were grown in test tubes in standard conditions on nutrient solution with addition of sucrose. Floating fronds only were inoculated. After about 12—16 days the whole surface had been covered with a dense assemblay formed by overlapping layers of floating vegetative fronds. Neverthless the number of immersed fronds increased only slightly above the average. Limitation of space is almost without action on the transformation of floating fronds into immersed ones.

7. *Turions*

Turions are formed in great numbers on nutrient solutions with sucrose (about 10 000 in one flask) after 4 weeks of growth. After 2 months this process is completed and the vegetative fronds perish. On nutrient solutions without sucrose the number of turions is considerably reduced (about 1500 for a flask) even after 7 weeks of growth. Their color is much lighter but they germinate in a normal way. Immersed vegetative fronds do not form turions.

Turions were germinated in light, darkness and in darkness interrupted by 10 minutes long illumination per day and transferred onto a fresh nutrient solution without and with 1% sucrose. Rising of turions from the bottom to the surface was considered the preliminary germination phase.

Turions of *Wolffia arrhiza* are able to germinate immediately after transformation without passing througth the resting stage.

The preliminary germination stage proceeds better on a nutrient solution without sucrose, already after 24 hours following inoculation the percent of germinated turions reaches 50 in light (fig. 7a). After 2 days already 97.9% of turions rise to the surface. In darkness this process proceeds at a lower rate but a daily 10 minutes long illumination with white light (1800 lux) suffices to increase the germination percentage to the level observed in continuous light. Turions which have remained on the bottom germinate as well but with considerable retardation; they forme immersed vegetative fronds not arising to the surface. In favourable conditions the percentage of germinated turions attains 98%.

On nutrient solution enriched with sucrose turions germinate slower. Darkness and 10 minutes long daily illumination depress considerably the percentage of germinated turions rising to the surface (fig. 7b). As the number of turions germinating with formation of immersed vegetative fronds is close to that of similar turions from nutrient solution

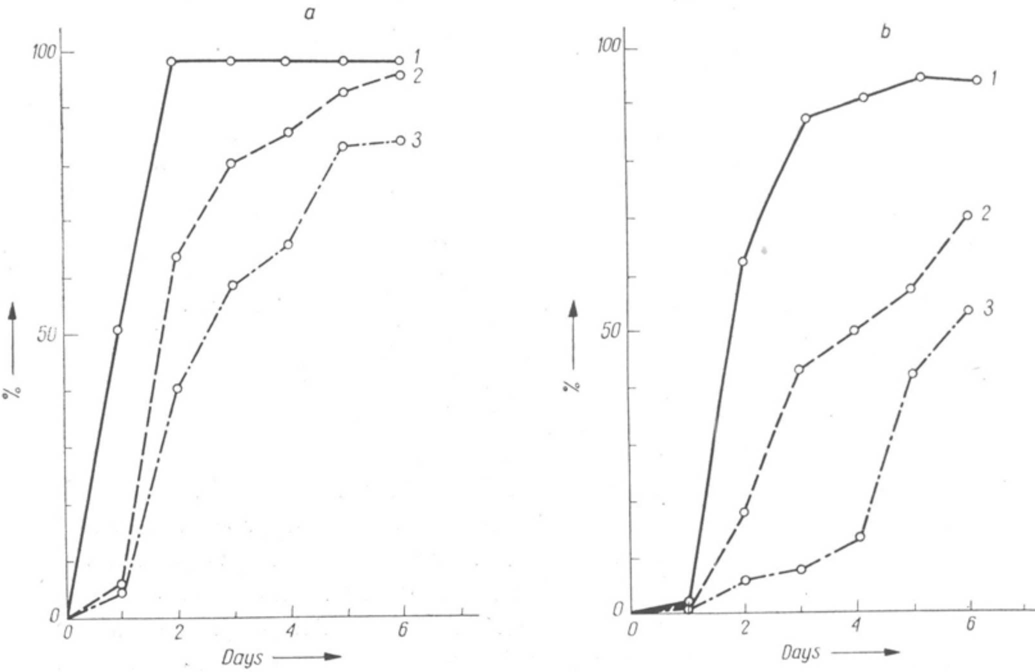

Fig. 7. Course of turion germination.

fig. 7a — Nutrient solution without sucrose, 1 — light (intensity 1800 lux), 2 — 10 minutes light per day, 3 — arkness. Abscissae—days of culture, ordinates — percentage of germanating turions.

fig. 7b — Nutrient solution with sucrose (1%). Denotation like in fig. 7a

without sucrose the total percentage of germination in darkness and 10 minutes long daily illumination is considerably lower.

After the preliminary germination stage — which for the majority of turions lead to a rising to the surface — turions begin to form secondary fronds in conformity with the growth dynamics given on in previous sections. 10 days following germination the culture on nutrient solution with sucrose showed a 87.8% increase of the number of floating vegetative fronds and 12% of immersed ones in relation to their initial numbers after germination. A similar increase (87% and 14.6%) was observed with cultures on nutrient solution without sucrose, though, as it has been shown in previous sections, lack of sucrose has an unfavourable influence upon the growth especially of immersed fronds. The present results are probably connected with a better germination on this kind of nutrient solution (without sucrose) and during further growth of the culture there appears a marked decrease especially of the growth rate of immersed vegetative fronds.

DISCUSSIONS

Wolffia arrhiza was cultured in conditions established on the grounds of the results presented in Landolt's (1957), Hillman (1961) and Czopek's (1959) papers. Czopek's investigations proved that optimum growth of *Wolffia arrhiza* is observed on Pirson's and Seidel's nutrient solution. Besides continuous ligth (Hillman 1961) is also very favourable factor for the development of the species of *Lemnaceae*. In light intensity 2000 lux the growth of *Wolffia arrhiza* reaches only 50% of its maximum value, whereas, in 9000 lux no difference appears between growth on nutrient solution without and with sucrose (Landolt 1957).

Optimum temperature for *Wolffia arrhiza* cultures is 26—28°C, minimum 13.5—16.5°C and maximum 30—31°C (Landolt 1957). Addition of sugar to the nutrient solution causes an increase of maximum temperature tolerated by the cultures. The optimum sugar concentration is 0.5—2% (Hillman 1961). Sucrose accellerates growth in all species of *Lemnaceae* in low light intensities (Landolt 1957). It is obvious that in darkness growth on a major scale is only possible on nutrient solution enriched with sucrose; good effects being also obtained by the addition of yeast extract (Landolt 1957, Hillman 1961). However if *Wolffia arrhiza* cultures grown in light are transferred into darkness they begin to divide intensely and the number of vegetative fronds attained increases considerably. Gorham too (1950, 1965) gives on a high value of growth rate for *Lemnaceae* during the first few days spent in darkness (inoculum effect).

According to Hegelmeier (1868) the first attempts at a numerical evaluation of the growth dynamics of *Wolffia arrhiza* were undertaken by Hoffman. The results of these calculations are, however, not exact since they are based on the wrong assumption that all the fronds produce continually secondary members at the same rate. Not all vegetative fronds, however, undertake growth; a part of them dies during culture, and a part undergoes transformation into immersed vegetative fronds.

In table I growth coefficients *K* obtained in the present research for *Wolffia arrhiza* are presented.

Hithero, in all papers on the *Lemnaceae* the fronds falling to the bottom were regarded as turions. Hegelmeier (1868) gives on that *Wolffia arrhiza* forms turions which ressemble normal vegetative fronds; during the vegetative period of growth, however, they produce great amount of starch which fills out tightly the cells, even those of the upper epidermis. Intercellular spaces decrease concomitantly and stomata close. The apex of the secondary bud develops at the early developmental stage and closes tightly the entrance to the pocket. If, however, the secondary frond develops in a normal way it can no more become hibernating one (Lawalree 1943). Landolt (1957) also reports in his papers that turions of *Wolffia arrhiza* do not differ externally from normal vegetative fronds and have an ability to form new turions.

Most probably these statements concern immersed vegetative fronds among which true turions as only slightly smaller are not well distinguishable. Turions never produce turions; at least two vegetative generations must stand between turion germination and formation of new turions (Hillman 1961).

Factors influencing favourably the formation of turions are a small area of the free surface; very dilute nutrient solution, high sugar content; i.e. conditions inhibiting the vegetative growth but allowing a high photosynthetic activity exceeding considerably the requirement of growth and respiration. Thus optimal growth conditions provided constantly can prolong the normal developmental cycle of the plant, whereas, a deterivation of these conditions accellerates the formation of turions (Czopek 1963). In natural conditions if nutrient substances are in sufficient amounts turions are formed only during a particular season of the year, i.e. from September to April (Henssen 1954).

The formation of turions of *Spirodela polyrrhiza* (L.) Schleiden in laboratory conditions starts between the 18-th and 27-th day of culture and is completed after 7 weeks (Czopek 1963). In *Wolffia arrhiza* this process proceeds in a similar way — it beginns between the 4-th and 8-th week of a culture on nutrient solutions with sucrose and after 7 weeks on nutrient solutions without this sugar. Formation of turions is not conditioned by a storage of a greater amount of starch. Turions of *Spirodela polyrhiza* (Henssen 1954) are also formed on nutrient solutions with maltose and a small amount of starch.

The resting period of *Spirodela polyrrhiza* turions can be considerably shortened by the action of low temperature. If, however, turions are kept in 20°C and in light, the germination percentage increases very slowly and attains 90% only after 9 months (Henssen 1954). Turions of *Wolffia arrhiza*, on the other hand, are able to germinate immediately after their formation and transfer to a fresh nutrient solution. Czopek (1959b) stated that turions never germinate on the same nutrient solution they were formed on. In darkness turions of *Spirodela polyrrhiza* germinate very slowly, they need about 15 days and the germination percentage does not exceed 50%. A daily 10 minutes long illumination is, however, sufficient to rise the germination percent to the level observed in continuous light. Thus, light plays here an olygodynamic role. Germination of turions of *Wolffia arrhiza* proceeds in a similar way and a daily 10 minutes long exposure to light accellerates this process considerably.

SUMMARY

1. *Wolffia arrhiza* was cultured on Pirson's and Seidel's mineral nutrient solution enriched with sucrose and without this sugar in light intensities of 500, 1800 and 5300 lux. Two forms of vegetative fronds: floating and immersed and a resting form (turions) have been distinguished.

2. Turions are only formed from floating vegetative fronds, in very great number on nutrient solutions with sucrose, in reduced number when allowed to grow on nutrient solution without sucrose. They differ from vegetative fronds by their size, fresh and dry weights, specific gravity, chlorophyll and starch content, resistance to unfavourable external conditions. They germinate well in light; a weaker germination with no resting stage is observed in darkness. Even small ammounts of light accelerate considerably germination in darkness.

3. Floating vegetative fronds grow well both on nutrient solutions without sucrose and enriched with 1% sucrose; a continuous transformation of floating vegetative fronds into immersed ones occurs only in presence of sucrose.

4. Nutrient solutions enriched with sucrose stimulate considerably the growth of immersed vegetative fronds, though their transformation into floating ones is only sporadic.

5. Independently of the composition of the nutrient solution both vegetative forms grow best if the initial ratio of floating and immersed fronds is 1 : 1.

6. The growth of vegetative fronds of *Wolffia arrhiza* exposed to light intensities of 500, 1800, 5300 lux as well as kept in darkness has been examined.

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Charakterystyka form wegetatywnych i spoczynkowych Wolffia arrhiza (L.) Wimm.

I. Wzrost i dynamika ich wzajemnych przemian

Streszczenie

1. Przeprowadzono hodowlę *Wolffia arrhiza* na pożywce Pirsona i Seidela, mineralnej i wzbogaconej sacharozą, w intensywności światła 500, 1800 i 5300 lux. W kulturach stwierdzono występowanie dwóch form pędów wegetatywnych (pływające i zanurzone) oraz formę spoczynkową — turiony.

2. Turiony powstają tylko z pędów wegetatywnych pływających bardzo licznie na pożywce z sacharozą, bez sacharozy w małej ilości. Różnią się od pędów wegetatywnych wymiarami, świeżą i suchą masą, ciężarem właściwym, zawartością chlorofilu i skrobi, odpornością na warunki zewnętrzne. Kiełkują dobrze na świetle, słabiej w ciemności z pominięciem okresu spoczynkowego. Nawet małe dawki światła znacznie przyspieszają kiełkowanie w ciemności.

3. Pędy wegetatywne pływające dobrze rosną zarówno na pożywce mineralnej bez sacharozy, jak wzbogaconej sacharozą (1%), lecz tylko w obecności sacharozy zachodzi stała przemiana pędów wegetatywnych pływających na pędy zanurzone.

4. Pożywka wzbogacona sacharozą wybitnie sprzyja wzrostowi pędów wegetatywnych zanurzonych, jednak przemiana ich na pędy pływające zachodzi tylko sporadycznie.

5. Niezależnie od pożywki najlepszy wzrost wykazują obie formy wegetatywne przy stosunku wyjściowym pędów wegetatywnych pływających do zanurzonych 1 : 1.

6. Zbadano wzrost pędów wegetatywnych *Wolffia arrhiza* w różnych intensywnościach światła: 500, 1800 i 5300 lux, oraz w ciemności.

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