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# RESONANT-LIKE DEPENDENCE OF YEAST GROWTH RATE ON MICROWAVE FREQUENCIES

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MICROWAVE biological effects caused by low intensities or strongly depending on frequency, especially showing a resonant response, are of fundamental interest for both (i) the application of the radiation and (ii) the understanding of biology in a general sense.

Prompted by the results of weak microwave radiation on yeast growth (Devyatkov, 1974) and by theoretical considerations predicting these observed biological responses in respect to frequency and intensity (Fröhlich, 1980) we investigated photometrically the growth rate dependence of *Saccharomyces cerevisiae* on frequencies near 41·8 GHz (Grundler *et al.*, 1977; Grundler & Keilmann, 1978) and found very remarkable effects (Fig. 1). At certain frequencies the growth rate remains unchanged, others cause an increase of up to 12% of the normalized and temperature-corrected growth rate or a reduction of the effect up to 29%. The most interesting fact is the occurrence of a multiplet of resonances between 41·64 and 41·79 GHz, each of them having a resonance line-width of only about 10 MHz.

Before taking further steps in the analysis of certain relevant physical and biological parameters, it is important to confirm these experimental findings using an improved set-up, which is briefly described.

## MATERIALS AND METHODS

The sharp frequency dependence calls for high precision in frequency stabilization and measurement. Phase locking to a quartz standard is obtained with a backward-wave tube, resulting in an output spectrum with up to 1 MHz width at 42 GHz.

Coupling of the microwave into the cell suspension occurs through a fork-shaped Teflon structure which has a surface of about 10 $cm^2$. Laser interferometric thermometry shows a maximum possible temperature difference between any points in the cell suspension of 0·02°C with 40 mW absorbed power (Keilmann, 1981).

The power absorbed ranges now from 6 to 34 mW and can be measured by 2 methods: (i) as the difference between the power of the wave running forward and backward in the waveguide and (ii) by determining the small increase in temperature (up to 0·5°C), caused by microwave heating within the sample cuvette built as a calorimeter and thermostatted by water. The mean absorbed power is determined as $P_{abs} = 84 \times \tau$ (mW) if $\tau$ in °C is inserted (see Fig. 2).

The temperature of the irradiated cell suspension is defined by $T = T_1 + 1{\cdot}32 \times \tau$. The dependence of the growth rate on temperature has been measured without irradiation between 31 and 34°C and amounts to a relative increase of 2·7% per °C at $T = 31$°C.

Light scattering is used to measure continuously the growing cell concentration. In 2 double-beam photometers 2 glass cuvettes of $1 \times 1$ $cm^2$ internal cross-section were inserted, one filled with medium (2·5 ml) and the other one with the cell suspension (wild-type, diploid, exponential phase, $10^5$ cells/ml) and a Teflon antenna. The photometer without microwave coupling serves as control. The slopes of the logarithmically replotted growth curves are the growth rates shown in the figures.

## RESULTS AND DISCUSSION

In order to examine microwave irradiation effects within the frequency range of 41,640–41,835 MHz we performed 83 growth experiments. We obtained a group

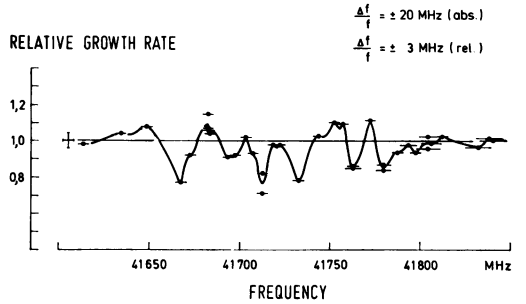


FIG. 1.—Relative growth rate of yeast cells in dependence on microwave frequency. The full line is plotted by a fit-programme (Grundler & Keilmann, 1978).

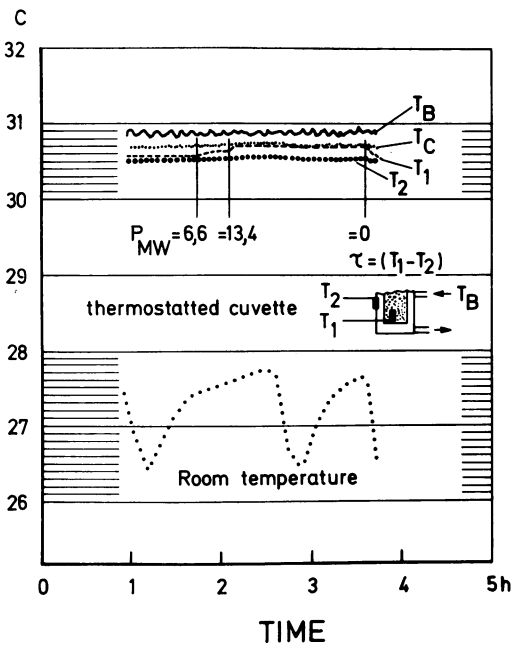


FIG. 2.—Plotter trace of differently registered temperatures. ($T_B$ thermostatted bath; $T_C$, control cuvette; $T_1$, surface of the irradiated cuvette; $T_2$, cuvette housing; $\tau=(T_1-T_2)$ is proportional to the absorbed microwave power.)

of control data (Fig. 3) and growth rate values influenced by the irradiation (Fig. 4). The growth rates of the non-irradiated controls (measured within a temperature interval of $30{\cdot}7 \pm 0{\cdot}1$°C) were found to be reproducible within a small scatter of $\pm 4\%$ on a relative scale, *i.e.* when the results of identical runs in both photometers are compared without applied radiation. This is illustrated by the vertical error bar in Fig. 4. The absolute uncertainty of controls increases to $\pm 10\%$. The relative growth rates of the irradiated samples and the corresponding controls can be seen in Fig. 4.

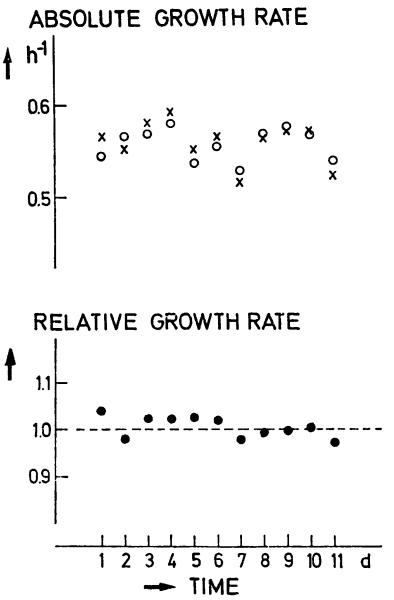


FIG. 3.—Absolute and relative growth rate $\mu$ of a series of control experiments using both photometers (x, 0). The normalization is defined as $\mu_x/\mu_0$.

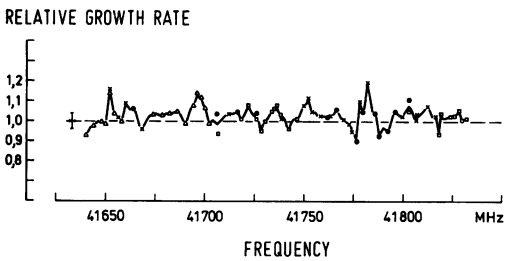


FIG. 4.—Relative growth rate of yeast cells in dependence on microwave frequency. The different symbols refer to different experimental series. The full line is plotted by a fit-programme.

In comparison to the former measured results (Fig. 1) one can qualitatively state:

(a) The values varying between 89 and 120% are of the same order of magnitude.

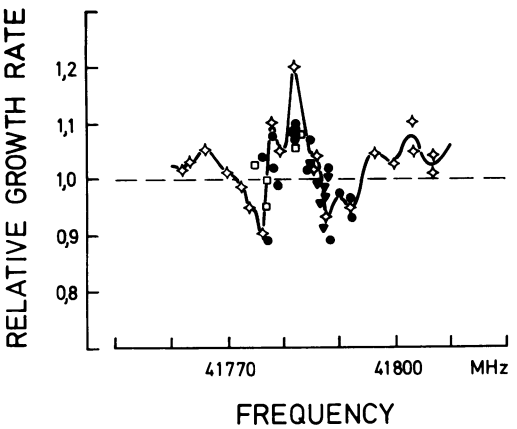


FIG. 5.—Dependence of the relative growth rate on frequency. Additionally to the curve out of Fig. 4 (◇), the values of 4 further runs are drawn.

(b) This fine tuning study shows again a strong frequency dependence.
(c) Furthermore a line width of nearly 10 MHz indicates a resonance-like behaviour.
(d) There is no correlation between the observed effects and the microwave power absorbed, within the range of 6–34 mW. Especially, positive effects are measurable at low intensities and negative effects at high intensities.
(e) An exact comparison with the results of Fig. 1. cannot be made directly, because of the absolute frequency uncertainty of ± 20 MHz. In general, however, the former effects are reproduced by the use of a set-up improved in many aspects.

The most remarkable effects have been measured within the frequency range of 41,770–41,795 MHz (Fig. 4). To test their reproducibility and to define the structure of a resonance we have performed a further set of 30 runs. The results are demonstrated in Fig. 5. In spite of the relatively broad scatter at the minima, indicating the influence of an until now unknown physical or biological parameter, the existence of a "resonance" structure of 10 MHz is confirmed once again.

In summary we reaffirm that there are changes in yeast growth rate, caused by low intensity microwave irradiation. These effects depend on frequency, showing a strong resonance-like behaviour, and are not correlated to the microwave power used. These effects are not explainable in terms of simple thermal response. To continue this investigation, the geometry of the irradiation antenna and also further dependent biological parameters should be changed both in order to get a stronger indication of the influence of the physical parameters and a better understanding of the resulting biological reactions.

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