The Molar Growth Yields of a Range of Micro-Organisms

It was reported by THORNTON[1] that when carbohydrate was the factor limiting growth in a medium, thirteen species of fungi gave a molar growth yield (MGY) of between 80 and 95 mg cellular material dry weight/m*M* of glucose utilized. One exception, *Dictyuchus sterile*, gave a MGY of half this value. Results obtained by PIRT and CALLOW[2] using *Penicillium chrysogenum* and by MORRIS[3] and WHITAKER[4] using aerobic bacteria are in agreement with a MGY of 80–95 mg. Previous studies on yield determination of fungi where carbohydrate was not the limiting factor indicated that a wide range of yields was to be expected (GRAY and BUSHNELL[5], LILLY and BARNET[6]).

The work described in this communication using organisms of widely differing phylogenetic affinities was to ascertain whether a constant yield could be obtained or whether there was a second group of organisms represented by *Dictyuchus sterile* in which the MGY was approximately half the first group. In the work to be described the yield of an organism was measured as dry weight. For bacteria and algae this was done by washing and centrifuging three times in weighed centrifuge tubes, and for fungi by filtration of mycelium onto weighed filter papers followed by washing then drying to constant weight.

The amounts of glucose which each micro-organism could fully utilize in the media were determined by growing the micro-organisms at different concentrations of glucose and plotting the yield of cellular material dry weight against glucose utilized. The concentration of glucose used in culture for each micro-organism must fall within the limits of the straight line portion of the graph produced by the method described above. The direct relationship between dry weight of micro-organism produced and the concentration of growth limiting substrate was first described by MONOD[7] for anaerobic bacteria.

As total carbohydrate utilization was the aim in all experiments it was found that the qualitative Benedict test for reducing sugars was adequate to determine the point at which complete utilization of carbohydrate occurred in the medium.

All fungi and the alga *Prototheca zopfii* were found to be able to totally utilize glucose at a concentration of 4 g/l medium.

Chlorella miniata and *Stichococcus bacillaris*, which were grown in total darkness, could not fully utilize more than 1 g/l, and two of the bacteria, *Sarcina lutea* and *Serratia marcescens*, were cultured at a glucose concentration of 2 g/l medium.

Results and discussion. From the results given in the Table the organisms examined appear to fall into two fairly well defined yield groups of 80–90 mg and 49–59 mg MGY.

It is unlikely that the lower yield group is the result of partial oxygen deficiency as all organisms were grown in shaking culture (120 oscillations per min, 4 cm throw) in flasks containing small volumes of medium (20 ml/100 ml conical flask), and, as stated, all carbohydrate concentrations were very low. The final pH values for used media in the low yield group of organisms did not fall below pH 5.5 except for *Aspergillus repens* (pH 4.4), and in most cases the final value rose about one half a pH unit higher than that of the unused media.

Although results above and below these two groups may be recorded, the standard deviation of the yield may account for this. Lower growth yields are, in addition, often associated with acid secretion leading to an inefficient utilization of substrate, e.g. *Prototheca zopfii*, *Aspergillus niger* (TERROINE and WURMSER[8]), and *Merulius lacrymans* (THORNTON[1] and unpublished). HADJIPETROU et al.[9] have shown the MGY of *Aerobacter aerogenes* to be 72.7 g but do not state the final pH of the medium.

Yields intermediate between the two groups have been recorded by SAMEJIMA and MYERS[10] for *Chlorella pyrenoidosa* (MGY of 66.5 g on glucose with nitrate as nitrogen source and 73.9 g with urea as nitrogen source), but throughout their experiments no test for total carbohydrate utilization was made. In addition glucose was supplied at a concentration of 10 g/l medium. They do, however, record a MGY of 88.4 g for *Chlorella ellipsoidea* on glucose with urea.

Though some yields well in excess of a MGY of 100 g have been recorded [*Ganoderma applanatum* 111 g, *Heliscus lugdunensis* 111 g on sucrose, *Tricladium splendens* 111 g on sucrose (THORNTON[1]), and *Torulopsis utilis* 108 g on glucose (OLSEN and JOHNSON[11])] it is doubtful that this constitutes a third yield group, but is due to an unusually high efficiency of conversion of carbohydrate to cellular material.

From the results obtained here and by other workers referred to in the text, at least thirty aerobic micro-organisms have been examined with glucose as the factor limiting growth in the medium. All organisms examined fall into the high yield group, except eight (including *Dictyuchus sterile*) which gave a uniformly low yield as shown in the Table. From these results and those of THORNTON[1] it is evident that yield is not related to phylogeny as demonstrated by the algae, bacteria, and fungi (especially phycomycetes) examined.

Zusammenfassung. Von 30 verschiedenen Mikroorganismen, in Substraten mit kleiner, wachstumsbegrenzender Zuckerkonzentration, kamen 23 auf ein Zellgewicht von 80–90 mg und 7 auf ein solches von 49–59 mg pro m*M* Glucose.

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Organism	MGY	Organism	MGY
1. *Ganoderma applanatum*	111.5	7. *Aspergillus repens*	49.5
2. *Collybia velutipes*	87.7	8. *Aspergillus fumigatus*	57.3
3. *Morchella esculenta*	85.4	9. *Rhizopus stolonifer*	56.5
4. *Nocardia α-type*	83.0	10. *Absidia glauca*	49.3
5. *Sarcina lutea*	90.9	11. *Chlorella miniata*	55.8
6. *Prototheca zopfii*	78.3	12. *Serratia marcescens*	54.3
		13. *Stichococcus bacillaris*	59.5

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