

literature survey

Comments on "Bioprocessing in space"

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An analysis developed by Westgate et al. for the digestible energy of edible and inedible biomass, including hydrolysis and fermentation, is reexamined with state-of-the-art values for the harvest index of hydroponic crops.

Keywords: Bioprocessing; digestible energy; hydrolysis; fermentation; hydroponic crops; space; harvest index

Westgate *et al.*¹ formalized an important consideration for the design of a Controlled Ecological Life Support System (CELSS) for space exploration and habitation. Namely, since a portion of a crop is inedible, savings can be derived from bioprocessing this otherwise inedible portion into additional food. In their example, bioprocessing reduced the crop growth area from 49 m²/person-day to 33 m²/person-day. This comment focuses on the role of the harvest index for these savings.

Harvest index is the ratio of edible to total biomass at crop maturity. For their example, Westgate *et al.* took a value for the harvest index of hydroponic wheat of $h = 0.2$, derived from hydroponic wheat experiments in which the harvest index failed to reach typical field values. However, as they noted, "If the relatively low edible fraction of the fast-growing hydroponic plants is increased, the amount of biomass requiring bioregenerative processing will be reduced." Subsequent experiments by the wheat investigators have succeeded in raising the harvest index of hydroponic wheat under high light conditions to about 0.45.² This number has also been achieved under optimal CO₂ by hydroponic soybeans.³ Another important candidate crop for CELSS is potatoes, which have been grown hydroponically with a harvest index of 0.8.⁴ Given the variety of values for the harvest index, and the analytical framework for bioprocessing spearheaded by Westgate *et al.*, it is valuable to generalize this framework as a potential design element for CELSS.

Westgate *et al.* established the dietary energy values of edible biomass and inedible biomass (after bioprocessing). Combining several of their terms and definitions to get to the heart of the issue, we can write

$$E_e = hv_e M \quad (1)$$

$$E_i = (1 - h)v_i M \quad (2)$$

$$E_e + E_i = E_t \quad (3)$$

where

E_e, E_i = respective daily energies obtained from edible and inedible harvested biomass, kcal/person-day

E_t = total daily energy requirements, kcal/person-day

h = harvest index, g edible/g total

v_e, v_i = respective specific digestible energy values of edible and inedible biomass, respectively, kcal/g

M = total biomass required to be grown, g/person-day (subscripted below: $v_i = 0$, without bioprocessing; $v_i > 0$, with bioprocessing)

To compare the biomass to be grown with waste biomass processing ($M_{v_i > 0}$) to its value without such processing ($M_{v_i = 0}$), compute M for these two conditions from equations (1-3) and set the two values for M in a ratio of biomass production, r . Analytically, r is therefore

$$r \equiv \frac{M_{v_i > 0}}{M_{v_i = 0}} = \frac{hv_e}{hv_e + (1 - h)v_i} \quad (4)$$

Using the review by Westgate *et al.* for the sequence of losses that enter into the v values, the values for v_e and v_i are, respectively, 3.4 and 0.4 kcal/g. The relatively low value for v_i comes from a sequence of conversion efficiencies, which include fractional recoveries for hydrolysis, fermentation, sugars used to make edible material, and final digestibility. Although none of the terms alone is exceptionally low, their cumulative product results in the above value.

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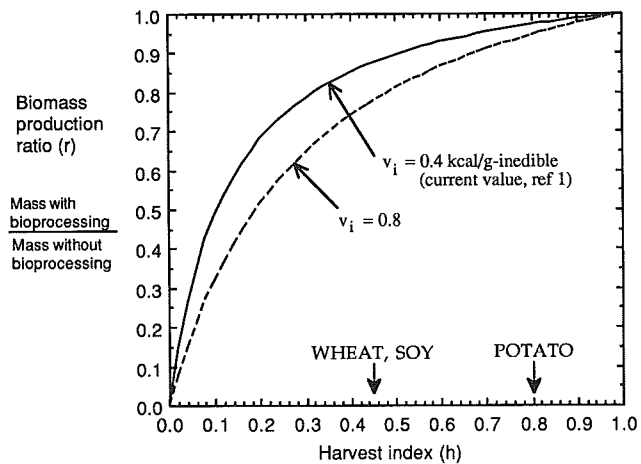


Figure 1 Plot of r as a function of h

In Figure 1, r is plotted as a function of h . For the case of $h = 0.2$ presented by Westgate *et al.*, $r = 0.67$ (i.e., $33 \text{ m}^2/49 \text{ m}^2$), demonstrating the substantial savings possible with bioprocessing. For higher values of h , the value of r increases and the savings concomitantly decrease. For example, when $h = 0.45$, currently possible with soybeans and wheat in the CELSS experiments, $r = 0.87$. In this case the savings in crop biomass production by using biomass processing (which translates directly into savings in the all-important design constraints of growth area and power for lighting) is about 13%. For values of $h = 0.8$ achieved with potatoes, $r = 0.97$, implying perhaps nearly negligible savings. A second curve for r —assuming that the digestible energy potential from bioprocessing the inedible biomass could be doubled from the typical value reported by Westgate *et al.*—is shown for comparison in Figure 1. The values of r for soybeans-wheat and potatoes, respectively, are 0.78 and 0.94.

Harvest index is only one measure of efficacy of a crop in a CELSS and will not alone drive optimal de-

signs; for example, nutritional values and high photosynthetic energy conversion over the entire life cycle are other important measures. However, it is clearly an ongoing research priority in the crop growth experiments to maximize the harvest index. The overall system of analysis presented by Westgate *et al.* is the kind of tool CELSS design engineers need to make tradeoffs among available options.

Although the processes that may limit its improvement are not well established, a high harvest index will always be a design goal, since, as Westgate *et al.* point out, additional equipment, volume, and power would be required for the procedures of separation, hydrolysis, and fermentation in processing the inedible biomass. The current crop values for the harvest index in Figure 1 limit the potential savings by biomass processing. Further improvements in the harvest index that would limit these savings even more could be balanced, however, by improvements in the yields along the various steps of the bioprocessing sequence (see Ref. 1 for details of these steps). The simplified system presented here may help focus issues about options for CELSS design.

Acknowledgements

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References

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