tobacco shoots will grow as well in submerged culture as a standard shake flask (three-day doubling time in both cases), provided that the liquid phase is well mixed. In Israel, commercial production of plantlets using totally submerged culture has been reported.

Although organ cultures have not yet been extensively exploited, they are promising vehicles for the production of some important secondary metabolites.

13.4. ECONOMICS OF PLANT CELL TISSUE CULTURES

Far fewer commercial processes for plant cell culture have been established than for bacterial, fungal, or animal cell cultures. Currently, four large-scale systems have been constructed in Japan and South Korea (1200 to 30,000 l) and one in Germany (75,000 l). In North America, the possible commercial development of three products is under active consideration.

As a rule of thumb, most commercial fermentations yield a revenue of about 20 ¢/l-day. If the volumetric productivity of a process is known, the wholesale price necessary to achieve this level of revenue can be estimated. Table 13.6 lists the published values of the volumetric productivities reported for some of the more intensely studied cell lines. Bulk prices in excess of $220/kg would be necessary to yield 20 ¢/l-day for these products.

13.5. SUMMARY

Plants produce a wide range of commercially important compounds. For some of these chemicals, plant cell tissue culture is a potential technique for their production. In addition, the bioreactor techniques that are applied to plant cell culture will be useful in the micropropagation of plants.

TABLE 13.6 Volumetric Productivities for Some Products Made in Plant Cell Culture and Their Corresponding Value

Product	Cell line	Productivity (g/l-day)	Bulk price to give 20 ¢/l-d revenue (¢/g)
Anthocyanin	Grape (Bailey alicant A, *Vitis* hybrid)	0.15	133
Berberine	*Thalictrum minus*[a] and	0.05	400
	Coplis japonica[b]	0.60	33
Diosgenin	*Dioscorea* spp.	0.0098	2040
Paclitaxel (Taxol)	*Taxus canadensis*	0.75	27
Podoverine	*Podophyllum versipelle*	0.15	133
Rosmarinic acid	*Coleus blumei*	0.91	22
Sanguinarine	*Papaver somniferum*	0.034	588
Shikonin	Lithospermum erythrorhizon	0.15	133

[a]Excreted into the medium, where it crystallizes.

[b]Continuous-flow system with cell retention; intracellular product.