products. The use of elicitors has been an important breakthrough in improving volumetric productivities in bioreactors. The most useful elicitor is methyl jasmonate. This compound is relatively inexpensive and readily introduced into large bioreactors. It regulates expression of a wide variety of plant genes.

Recent advances in genomics and our understanding of plant molecular biology make it possible to consider genetically engineering the plant cell's biosynthetic pathways. It will soon be possible to redirect these toward desired chemicals.

## 13.3. BIOREACTOR CONSIDERATIONS

### 13.3.1. Bioreactors for Suspension Cultures

Many of the differences between plant cell cultures and microbes have direct implications for the design and scale-up of suspension culture systems (see Table 13.2). In particular, the degree of physical mixing that is desirable is important. However, the basic reactor types we discussed in Chapter 10 can usually be adapted to plant cells.

Plant cells are large, and when they are exposed to turbulent shear fields where the eddy size approaches the cell size, the cells can be exposed to a twisting motion that can damage them. Lower levels of shear appear to affect cell surface receptors and nutrient transport. Reactors with high shear must be avoided. However, plants cells can withstand far more shear than animal cells, and shear-tolerant lines can sometimes be developed. Stirred tanks designed for the culture of bacteria are not good choices, but modified stirred tanks can be suitable. Reactors up to 75000 l have been used successfully.

Plant cell cultures can achieve high cell densities and viscosities. Their reduced respiration rate, however, compensates in part for the need for vigorous agitation. Airlift reactors for low or moderate cell densities (< 20 g dry wt/l) or paddle-type or helical-ribbon impellers for high-cell-density systems have been advocated as reactors that strike a good compromise between the need for good mixing and the shear sensitivity of plant cells.

More important than actual shear damage is the role that mixing plays in the biological response of some systems to scale-up. In at least some cases, the formation of aggregates appears to be necessary to achieving the mix of cell types essential for good

**TABLE 13.2** Differences between Plant Cells and Microbes and the Implications for Bioreactor Design

| Differences | Implications for reactor design |
|---|---|
| Lower respiration rate | Lower $O_2$ transfer rates required |
| More shear sensitive | May require operation under low-shear conditions |
| Cells often grow as aggregates or clumps | May have mass transfer limitations that limit the availability of nutrients to cells within the aggregate |
| Degree of aggregation may be important with regard to secondary metabolism | May be an optimal aggregate size for product synthesis |
| Volatile compounds may be important for cell metabolism (e.g., $CO_2$ or ethylene) | May need to sparge gas mixtures |

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