space, optimizing light, and maintaining high plant populations (in some systems) for uniform, high-quality production.

4.7 Biotechnology

4.7.1 Micropropagation

The application of biotechnology in *Gomphrena* production, specifically regarding micropropagation, has historically seen limited documentation; however, established protocols now utilize specific tissue culture techniques to enhance multiplication rates. Research indicates that callus induction is most successful when utilizing hypocotyl tissues as explants (Ruiz and Valadez, 1985). These are typically cultured on a basal Murashige and Skoog (MS) medium enriched with sucrose at concentrations of 3%, 5%, or 7%. To achieve successful morphogenesis, a precise hormonal balance is required: a combination of 10^{-5} M NAA (Naphthaleneacetic acid) and 10^{-8} M BA (Benzyladenine) effectively induces shoot growth, although higher sucrose levels (5% to 7%) are generally necessary to stimulate concurrent root development. Furthermore, aseptic seedlings provide viable leaf and stem segments which, when placed on gelled MS medium supplemented with BA alone or in combination with auxins, serve as efficient starting points for mass propagation.

4.7.2 Molecular markers

Molecular marker technology has become an important tool for characterizing genetic diversity and supporting breeding programmes in gomphrena. Random Amplified Polymorphic DNA (RAPD) markers have revealed approximately 94.38% polymorphism, confirming the existence of substantial genetic variation among cultivated genotypes (Fatinah et al., 2012). Such information facilitates parent selection, germplasm conservation, and the development of improved cultivars with superior ornamental and agronomic characteristics.

5 Conclusion

Recent technological advancements have transformed the cultivation and commercial production of *Tagetes erecta* and *Gomphrena globosa* by improving productivity, quality, and adaptability under diverse growing conditions.In marigold, progress in hybrid seed production, male sterility systems, molecular breeding, tissue culture, and stress-resilient breeding has accelerated the development of superior cultivars suitable for commercial production. Likewise, innovations in gomphrena production, including improved cultivation practices, biofertilizer application, plant growth regulators, high-density planting, and advanced drying technologies, have enhanced flower productivity and value addition.

The integration of biotechnology, precision cultivation, integrated nutrient management, and modern post-harvest handling techniques has contributed to sustainable and profitable flower production systems. Furthermore, the use of environmentally friendly approaches such as biofertilizers, integrated pest management, and efficient irrigation practices supports sustainable floriculture development under changing climatic conditions. Continued research and adoption of these advanced technologies will play a vital role in improving productivity, maintaining flower quality, and strengthening the commercial potential of marigold and gomphrena in both domestic and international markets.

Authors' contributions

SS, AP and AA were involved in conceptualization, methodology, editing, writing the original draft, manuscript revision and providing the final structure to the manuscript. All authors read and approved the final manuscript.

References

Akbar S.H., and Sahare H., 2024, Advanced dehydration techniques standardized for flowers of *Gomphrena globosa* L., Asian Journal of Soil Science and Plant Nutrition, 10(3): 533-539.
https://doi.org/10.9734/ajsspn/2024/v10i3365

Ayiecho P.O., and Nyabundi J.O., 2025, Development of pure line varieties, In: Conventional and Contemporary Practices of Plant Breeding, Cham: Springer Nature Switzerland, pp. 157-173.
https://doi.org/10.1007/978-3-031-74998-8

Babaei K., Moghaddam M., Farhadi N., and Pirbalouti A.G., 2021, Morphological, physiological and phytochemical responses of Mexican marigold (*Tagetes minuta* L.) to drought stress, Scientia Horticulturae, 284: 110116.
https://doi.org/10.1016/j.scienta.2021.110116