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Metabolomic profiling for quality enhancement in fruits and vegetables

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Abstract: -

Metabolomic profiling has emerged as a powerful approach for improving the quality and nutritional value of fruits and vegetables. It involves the comprehensive analysis of small molecules or metabolites that reflect the physiological and biochemical status of plant tissues. These metabolites, including sugars, organic acids, amino acids, phenolic compounds, vitamins and pigments, play important roles in determining key quality traits such as flavour, colour, aroma, texture and nutritional content. Advanced analytical techniques enable the identification and quantification of these metabolites, helping researchers understand metabolic pathways associated with fruit and vegetable quality. Metabolomic studies also facilitate the identification of biomarkers linked with desirable traits such as enhanced nutritional composition, stress tolerance and longer shelf life. Integration of metabolomics with other omics approaches supports crop improvement programs and the development of superior cultivars. Furthermore, metabolomic profiling assists in monitoring postharvest changes and ensuring product authenticity, thereby contributing to sustainable horticultural production and improved human nutrition.

Keywords: *Metabolomic profiling, metabolites, fruits, vegetables and quality enhancementetc.*

What is Metabolomic profiling?

Metabolomic profiling is the comprehensive analysis of small molecules (metabolites) present in a biological sample. In fruits and vegetables, these metabolites include sugars, organic acids, amino acids, phenolics, vitamins, flavonoids and volatile compounds that determine taste, aroma, nutritional value, texture and stress response (Arbona *et al*., 2013). Metabolomic profiling is increasingly being used to enhance the quality of fruits and

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vegetables by identifying biochemical markers linked to flavour, nutrition, shelf life and stress tolerance. It provides a detailed snapshot of metabolites—small molecules like sugars, organic acids, amino acids and secondary metabolites—that directly influence sensory and nutritional quality (Fiehn, 2002). The "food metabolome" includes all small molecules (<1500 Da) present in a plant sample (Johanningsmeier *et al*., 2016).

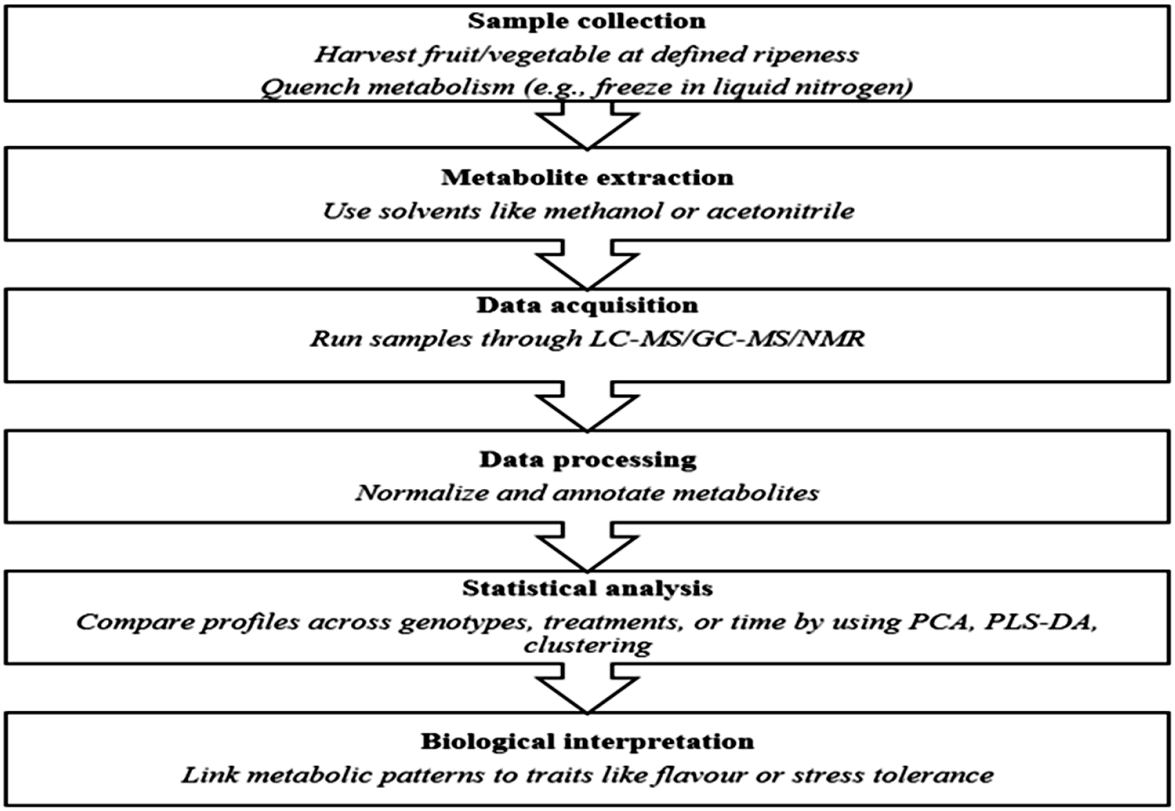
In fruits and vegetables, this profile is a direct reflection of the phenotype, capturing the complex interaction between the plant's genetic makeup and its environment (Singh *et al*., 2022).

Metabolomics uses analytical methods:

- Gas Chromatography–Mass Spectrometry (GC-MS).
- Liquid Chromatography–Mass Spectrometry (LC-MS).

Technology	Strengths	Use case in quality
GC-MS	High sensitivity for volatile organic compounds (VOCs).	Profiling aromas in apples, berries and tomatoes (Pott *et al*., 2020).
LC-MS	Wide coverage of polar and non-polar secondary metabolites.	Analyzing flavonoids, carotenoids and alkaloids (Gao *et al*., 2021).
NMR	Non-destructive, highly reproducible, easy sample prep.	Tracking sugar/acid ratios in pomegranates during storage (Shezi *et al*., 2024).

How metabolomic profiling work? (Hall, 2011)



- Nuclear Magnetic Resonance (NMR)

Why is metabolomic profiling important for quality enhancement?

Metabolomics for enhancing organoleptic traits

Flavour is a complex trait determined by sugars, organic acids and volatiles. Metabolomics allows researchers to move beyond simple "Brix" measurements to understand the "flavoursome." Examples: In tomatoes, specific apocarotenoid volatiles (like geranial) were linked to "sweetness" perceptions, even when sugar levels remained constant (Kumar *et al*., 2017). In citrus, metabolomics has been used to map variations in flavonoids and coumarins across different species and developmental stages (Singh *et al*., 2022).

Post-harvest quality and shelf-life extension

Metabolic changes continue after harvest, often leading to senescence or "off-flavours" (Pott *et al*., 2020).

- **Biomarkers for decay:** In stored apples, increased levels of mannose and xylose serve as biomarkers for cell wall hemicellulose breakdown, signalling the onset of senescence before it is visible to the eye (Kumar *et al*., 2017).
- **Controlled Atmosphere (CA) Storage:** NMR-based metabolomics has shown that pomegranates stored under low-pressure conditions maintain higher sucrose and lower ethanol levels compared to traditional modified atmosphere packaging, directly correlating to better taste and longer shelf life (Shezi *et al*., 2024).

Applications in quality enhancement (Rajan *et al*., 2023; Dadwal *et al*., 2024)

Flavour and aroma improvement

Profiling helps identify volatile compounds and sugars responsible for taste and aroma, guiding breeding programs for better consumer acceptance.

Nutritional value

Metabolomics reveals bioactive compounds such as antioxidants, vitamins, and phenolics, enabling selection of varieties with higher health-promoting properties.

Post-Harvest management

By monitoring metabolic changes during storage and ripening, metabolomics supports strategies to extend shelf life and reduce spoilage.

Stress and disease resistance

Identifying metabolites linked to stress tolerance or pathogen resistance helps develop resilient cultivars without compromising quality.

Precision breeding

Integration of metabolomic data with genomics accelerates marker-assisted breeding for targeted quality traits.

Challenges and future perspectives

Metabolomic profiling has become an important approach for improving the quality of fruits and vegetables by enabling comprehensive analysis of metabolites responsible for flavour, aroma, nutritional value, colour and stress tolerance. Through advanced analytical techniques such as mass spectrometry and nuclear magnetic resonance, metabolomics helps identify key biochemical compounds and metabolic pathways that influence quality traits and post-harvest performance. This information supports plant breeders and researchers in developing improved cultivars with enhanced nutritional value, better taste, longer shelf life and greater resistance to environmental stresses. In the future, the integration of metabolomics with other "omics" technologies such as genomics, transcriptomics and proteomics will provide deeper insights into the complex mechanisms regulating fruit and vegetable quality. Additionally, the application of artificial intelligence, high-throughput analytical tools and precision agriculture will further accelerate quality improvement programs. Thus, metabolomic profiling holds great promise for advancing sustainable crop improvement, ensuring food quality, and meeting the growing consumer demand for nutritious and high-quality horticultural produce.

References

1. Arbona, V., Manzi, M., Ollas, C. and Gomez-Cadenas, A. (2013). *Plant physiological drought responses unravelled by metabolomics*. ***Trends in Plant Science,*** **18**(5): 237-245.
2. Dadwal, V., Aroor, M. S., Joshi, R. and Gupta, M. (2024). Recent progress in metabolomics research: insights into fruit metabolome, harvesting techniques and health-promoting bioactives. *International Journal of Food Science and Technology*, **59**(8): 5285-5302.
3. Fiehn, O. (2002). *Metabolomics-The link between genotypes and phenotypes*. ***Plant Molecular Biology,*** **48**(1-2): 155–171.
4. Gao, Y., Hou, L., Gao, J., Li, D., Tian, Z., Fan, B., Wang, F. and Li, S. (2021). Metabolomics approaches for the comprehensive evaluation of fermented foods: A review. *Foods*, **10**(10): 2294.
5. Hall, R. D. (2011). *Plant metabolomics in a nutshell: Potential and future challenges*. ***Comptes Rendus Biologies,*** **334**(9): 839-844.
6. Johanningsmeier, S. D., Harris, G. K. and Klevorn, C. M. (2016). Metabolomic technologies for improving the quality of food: Practice

and promise. *Annual Review of Food Science and Technology*, 7: 413-438.

7. Kumar, R., Bohra, A., Pandey, A. K., Pandey, M. K. and Kumar, A. (2017). Metabolomics for plant improvement: Status and prospects. *Frontiers in Plant Science*, 8.

8. Pott, D. M., Vallarino, J. G. and Osorio, S. (2020). Metabolite changes during postharvest storage: Effects on fruit quality traits. *Metabolites*, **10**(5): 187.

9. Shezi, S., Ngcobo, M. E. K., Khanyile, N. and Ncama, K. (2024). Physio-metabolic mechanisms behind postharvest quality deterioration in broccoli (*Brassica oleracea* var. Italica) and Swiss chard (*Beta vulgaris* L. var. Cicla): A review. *Plants*, **13**(22): 3174.

10. Singh, D., Bisen, M., Shukla, R., Prabha, R., Maurya, S., Reddy, Y., Singh, P., Rai, N., Chaubey, T., Chaturvedi, K., Srivastava, S., Farooqi, M., Gupta, V., Sarma, B., Rai, A. and Behera, T. (2022). Metabolomics-driven mining of metabolite resources: Applications and prospects for improving vegetable crops. *International Journal of Molecular Sciences*, **23**(20): 12062.