Omics Approaches in Insect Science

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ABSTRACT

The immense threat posed to the environment due to anthropogenic activities has led to thinking about novel strategies for management of insect pests. Omics is a general term used to describe several rapidly growing fields of science that study large sets of biological molecules. It incorporates the 'omics' methods allowing identification of genes (genomics) along with their RNA (transcriptomics), proteins (proteomics) and metabolites (metabolomics) expression levels. Modern era omic-approaches viz., genomics, proteomics, transcriptomics, peptidomics, QTLomics, metabolomics and fluxomics provide insights into the molecular mechanisms of insect resistance to pesticides, changes in cell physiology, plant defense responses against insect attack, cellular strategies to fight against pathogens, role of gene expression in the divergence of insect biotypes, colour forms and the tolerance of plants to insects for better pest management.

INTRODUCTION

Plants are sessile organisms and continuously face harsh environmental conditions and biotic invasions in their natural habitat. The interaction of biotic factors with plants can be both beneficial and deleterious, impacting population dynamics, plant-insect co-evolution, and ecosystem nutrient cycling. Among all the biotic invaders, insects have been recognized to be the most significant herbivores because almost half of the total 6 million insect species are herbivorous. Herbivorous insects have evolved a variety of feeding mechanisms to acquire nutrients from their host plants (Zogliet al., 2020).

In response to herbivory, plants have developed various morphological, biochemical, and molecular-level defense survival strategies. Plants produce various toxins and defense proteins that target physiological processes in the insect. The biochemical and molecular mechanisms of defense against herbivores are diverse, highly dynamic, and are mediated by both direct and indirect defenses. Plant biologists have extensively used high-throughput omics techniques (eg., genomic, proteomic, transcriptomic, metabolomic, phenomic, interactomics, ionomic, etc.) in their research on plant-insect interactions. Each of these omics approaches on its own can provide useful and novel information about plant-insect interactions, but data from several approaches may also be integrated to facilitate the identification of genetic traits underlying a given phenotype.

Different types of omics

Genomics - The study of the genomes of any organism is called genomics. It is used for the recognition of genes involved in insect resistance and biotype development and to develop crops resistant to pests. Or expression of genes related to insecticide susceptibility, and colour morphs (Liet al., 2016).

Transcriptomic - Plants activate defense mechanisms when being attacked by insect pests, many of which involve transcriptional reprogramming. The study of the transcriptome also referred to as expression profiling, examines the expression levels of mRNA transcripts in a given organism, organ, tissue, or cell population, often using high-throughput techniques based on DNA microarray technology(Wang et al., 2020).

Metabolomics - The plant produces a wide range of metabolites that can be used for improving crop resistance to various stresses and helps to know the symbionts in the gut (Liu and Zhu, 2020).

Peptidomics - Neuropeptides are important messenger molecules (0.5–5 kDa) that influence nearly all physiological processes. Ininsects, they can be released as neuromodulators within the central nervous system (CNS) or as neurohormones into the hemolymph.

Proteomics - In recent years, researchers have been increasingly using the proteomics approach to understand the plant resistance mechanisms to sap-sucking insect pests. The role of specific proteins involved in plant-insect interactions is yet to be determined (Scott et al., 2021).

QTLomics include the integration of classical QTL mapping and identification/ characterization of genes/ metabolites/proteins that contribute to the underlying quantitative trait.

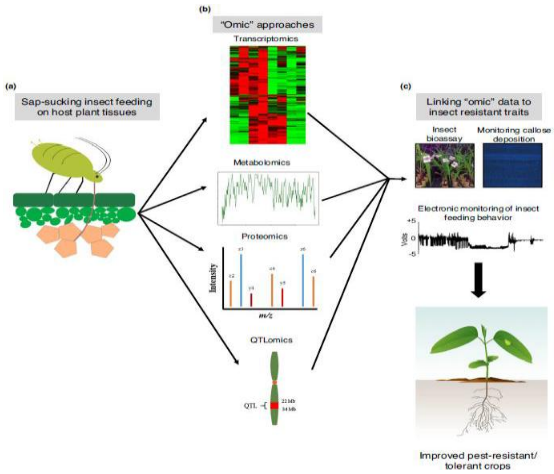

Figure 1: Ento (o)mics to understand plant defense against sap-sucking insect pests

Plants are constantly challenged by insect pests that can dramatically decrease yields. Insects with piercing-sucking mouthparts, for example, aphids, whiteflies, and leaf hoppers, seemingly cause less physical damage to tissues, however, they feed on the plant's sap by piercing plant tissue and extracting plant fluids, thereby transmitting several plant pathogenic viruses as well (Zogliet al., 2020). As a counter-defense, plants activate an array of dynamic defense machinery against insect pests including the rapid reprogramming of the host cell processes. For a holistic understanding of plant-sap-sucking insect interactions, there is a need to call for techniques with the capacity to concomitantly capture these dynamic changes. Recent progress with various 'omic' technologies possesses this capacity (Fig. 1). Omic approaches provide a concise summary of the application of 'omic' technologies and their utilization in plant and sap-sucking insect interaction studies. The study provides a perspective on the integration of 'omics' data in uncovering novel plant defense mechanisms against sapsucking insect pests.

Omic approaches in insect science

- Helps us to identify the genes involved in the resistance of plants and insects.
- Play an important role in gene expression in the divergence of insect biotypes, colour forms and adaptive evolution of insect populations (Tiwari et al., 2013).
- Determines the degradation ability of micro-organisms to insecticides.
- Molecular mechanisms underlying insect resistance to pesticides can be confirmed.
- Provides information about changes in the cell physiology of plants against pesticide exposure.
- It helps to identify the microbial symbionts in the gut and environment.
- Knowledge generated from omic techniques can also be used for integrated pest management and also used for developing plant-based insect repellents or eco-friendly green pesticides.

Multi-omic approaches inform - genotype to phenotype cascade

The highly complex hierarchical organization of plant systems and the importance of the integrative systems approach to study plant-insect interaction have been known through multi-omic approaches (Crandall et al., 2020). In a recent integrative study to analyse herbivore-induced changes in plants, combinations of genome-wide gene expression, defense-related pathways, and secondary metabolite profiles were monitored. The results showed that plant responses were not influenced by the degree of specialization of insect herbivores, but were more strongly regulated by their different feeding modes (Fig. 2). The multi-omic study helps in knowing the genotype to phenotype cascade.

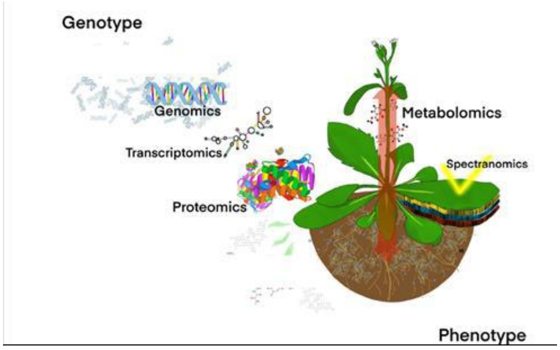

Figure 2: Multi-omic approaches

Challenges in Integrated Omics

- It includes experimental challenges i.e., sample preparation.
- Choice of the integration approach depends on the study design.
- Lack of flexibility in the integration of different omic methods and requires time.
- Data integration and interpretation of results are difficult.
- Lack of biological knowledge, biomarker development and phenotypic prediction is not easy.

CONCLUSION

To meet future agricultural challenges using sustainable technologies, it is imperative that holistic approaches based on a detailed understanding of plant defense mechanisms be used to develop crops that can naturally resist herbivore attacks. Although significant progress has been made in understanding the plant responses to insect pests, linking resistance responses and phenotypes to genes and metabolic/genetic pathways in plants in response to insect attack is one of the bottlenecks in identifying and characterizing resistant traits. The information gained from the omic study could provide a better understanding of genes, proteins and metabolites expression and thus helps in the integrative management of pest.

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