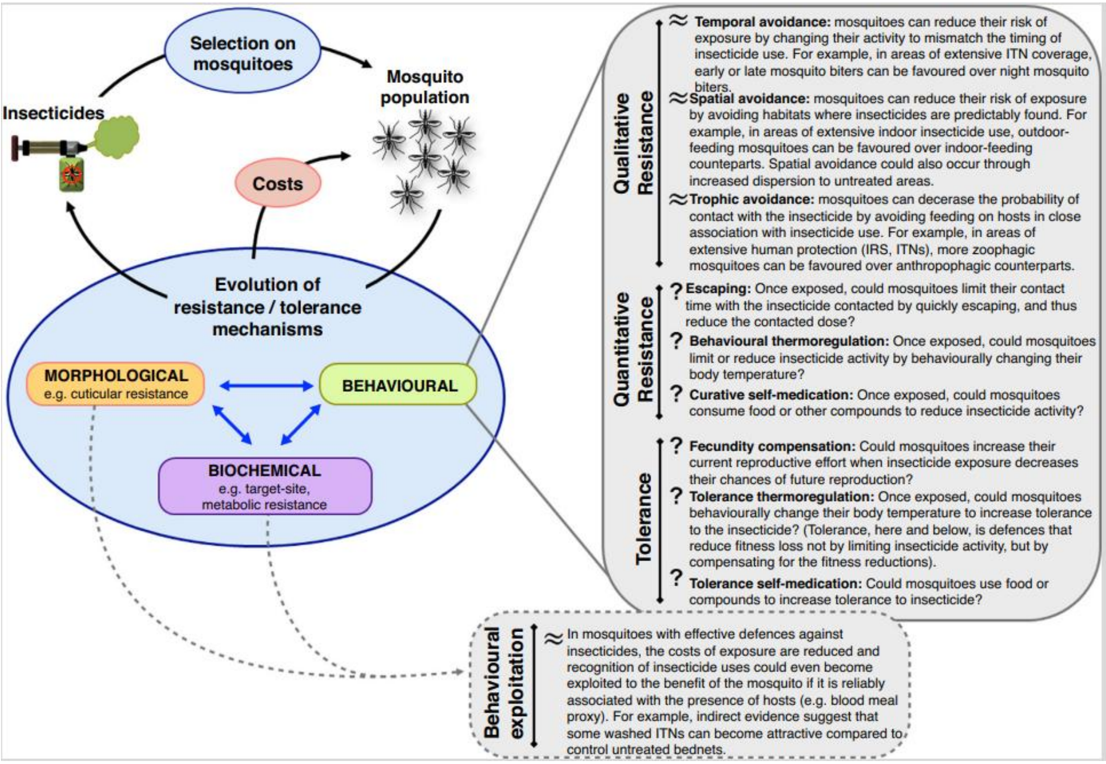

Figure 3 Expanding the field of mosquito insecticide resistance (Adopted from Benelli and Beier, 2017)

5.2 Biotechnological approaches

Biotechnological innovations are revolutionizing mosquito control by targeting vector populations at the genetic level. Gene drive systems use engineered genetic elements to spread traits through mosquito populations rapidly, such as reducing fertility or blocking pathogen transmission. This approach holds promise for sustainable suppression or modification of vector populations but requires careful assessment of ecological risks and ethical considerations before widespread deployment (Jones et al., 2020; Wang et al., 2021). Complementing gene drives, RNA interference (RNAi) technology enables selective silencing of essential mosquito genes involved in survival or reproduction, offering a species-specific bioinsecticide strategy with minimal off-target effects (Yadav et al., 2023).

RNAi-based methods have demonstrated effectiveness in laboratory settings by targeting genes critical at various developmental stages of mosquitoes. Delivery mechanisms include microinjection, feeding, or topical application of double-stranded RNA molecules designed to trigger gene silencing pathways. While promising, challenges such as stability of RNA molecules in field conditions and efficient delivery to wild mosquito populations must be addressed to realize practical applications. Together with gene drives, RNAi represents a cutting-edge toolkit for integrated vector management aiming to overcome limitations of traditional control methods (Wang et al., 2021; Yadav et al., 2023).

5.3 Advanced formulations and delivery systems

Nanotechnology offers innovative solutions for enhancing the efficacy and sustainability of mosquito control agents through advanced formulations and delivery systems. Nanopesticides formulated with plant-derived compounds or synthetic insecticides improve solubility, stability, and controlled release profiles, thereby increasing target specificity while reducing environmental contamination. These nanoformulations can penetrate mosquito cuticles more effectively or provide prolonged residual activity on treated surfaces compared to conventional products (Benelli et al., 2018; Kumar et al., 2020).

Moreover, nanocarriers enable novel delivery strategies such as slow-release larvicides in breeding habitats or attract-and-kill devices that exploit mosquito behavior for targeted control. Despite their potential benefits,