

Development & Deployment of a Universal Training Population System (TPS) for Accelerating Alfalfa Genomic Selection

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Traditional alfalfa breeding programs rely on recurrent phenotypic selection. While this approach has successfully improved resistance to various biotic stresses, it remains inefficient for enhancing complex, multigenic traits such as forage yield, quality, and stand persistence. Although a unified 3,000-marker DArTag panel released in 2023 has enabled more standardized genotyping, resulting data remain fragmented across breeding programs and institutions. To address this bottleneck, we are developing and deploying a universal Training Population System (TPS) designed not only to generate genomic prediction models but also to deliver them through accessible, breeder-ready tools. The TPS integrates genotypic and phenotypic data from over 10,000 alfalfa genotypes across 14 diverse research projects. To date, we have characterized the genetic diversity and population structure of more than 5,800 genotypes across six breeding projects, tracing genetic shifts from Plant Introduction (PI) accessions to pre-breeding and advanced populations. Our results reveal a population structure by breeding projects and a loss of up to 10% in genetic diversity during the transition from genebank accessions (PIs) to pre-breeding populations, with stabilization in later cycles. By utilizing microhaplotypes for allele mining, we identified several alleles in populations associated with plant architecture, winter survival, and potato leafhopper resistance. The next phase will focus on implementing a robust genomic prediction platform that incorporates genotype-by-environment interactions and genetic distance between populations using a flexible kernel function to generate Genomic Estimated Breeding Values for ten agronomic traits. The overarching goal is to deploy the TPS in a form that breeders can routinely use. Consequently, we will focus on ensuring that TPS outputs transition from research manuscripts to practical decision-support tools with high predictive performance and a meaningful impact on alfalfa improvement. This universal TPS represents a highly collaborative effort supported by multiple universities, USDA ARS units, and private sector partners. Its successful deployment will significantly accelerate alfalfa breeding by enabling data driven parent selection, shortening breeding cycles, and democratizing access to genomic selection resources across North America.