adaptation differences. In practice, the analysis process may include tests of normality, calculation of environment-wise and pooled means, and partitioning of total variation into species, environment, and species-by-environment interaction components. This step provides the statistical basis for deciding whether the comparison of yield stability among legume species in Zhejiang is meaningful.

After ANOVA, the study should combine AMMI and GGE biplot analysis, because these two methods are widely used and complementary in interpreting genotype-by-environment interaction (Zhang et al., 2025). GGE biplot is especially useful for identifying winning genotypes, judging mean-versus-stability performance, and screening discriminating or representative test environments, while AMMI is more effective for decomposing interaction effects and deriving indicators such as ASV. To strengthen the robustness of conclusions, the results can further be compared with regression-based methods such as Eberhart-Russell analysis and with integrated ranking procedures such as WAASB, YSi, or average rank, because different methods may emphasize either responsiveness, static stability, or broad adaptation. In this way, the final methodological framework can achieve a more balanced evaluation of both yield level and yield stability among different legume species in Zhejiang. Overall, the data sources, evaluation indicators, and analytical methods for this study should all serve the same goal: comparing yield stability among different legume species in Zhejiang under realistic multi-environment conditions. A design centered on replicated field trials, multi-index stability evaluation, and combined ANOVA-AMMI-GGE analysis is well aligned with the research question.

4 Comparison of Yield Variation Characteristics among Different Legume Crops

4.1 Differences in long-term average yield among different legume crops

Across legume crops, long-term average yield differs substantially among species, and the basic pattern in the literature is that soybean usually ranks among the highest-yielding grain legumes, while some lupins or minor legumes remain clearly lower-yielding. In a direct species comparison, soybean averaged 3.99 $t \cdot ha^{-1}$ and had the highest seed yield among the tested legumes, whereas narrow-leafed and yellow lupin had the lowest yields. Long-term evidence from northern Europe also showed that narrow-leafed lupin yielded on average 11% more than faba bean and 25% more than pea, while faba bean still averaged 11% higher than pea, indicating that the ranking among non-soybean legumes can change by species and environment. For Zhejiang, this suggests that interspecific yield comparison should not assume a single universal order, but should distinguish between high-yielding species, moderate-yielding species, and species with lower but potentially more specialized adaptation (Figure 2).

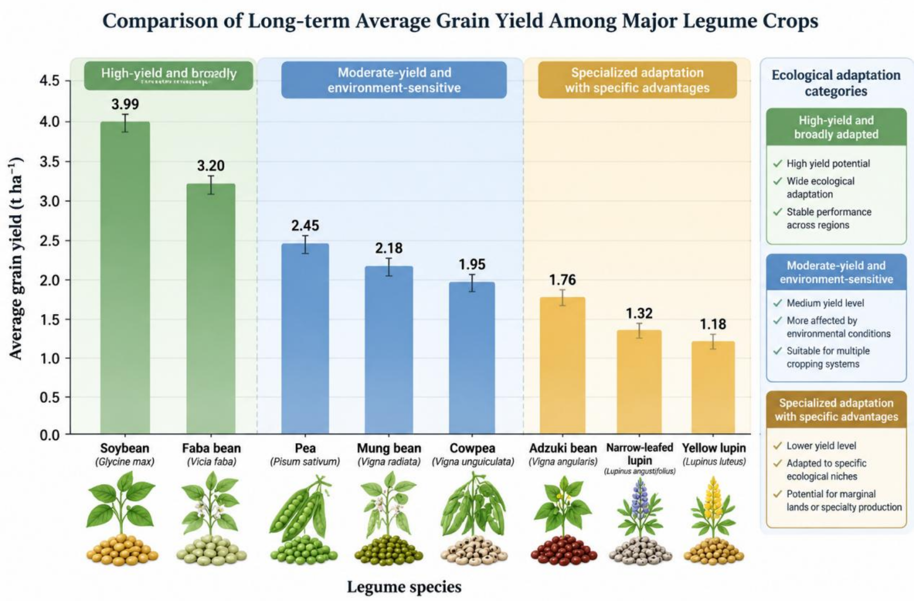

Figure 2 Comparison of long-term average yield performance among major legume crops and their ecological adaptation categories. The figure summarizes differences in yield potential and emphasizes that productivity ranking varies among species and environments