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Stability analysis of promising groundnut genotypes across multiple environments

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Abstract

A groundnut genotype that tops the yield chart at one location may fall to the bottom at another—a frustrating reality for breeders trying to release broadly adapted varieties. This research assessed yield stability of 14 groundnut genotypes across six environments in Tuscany, Italy, over three growing seasons (2022-2024). The AMMI (Additive Main Effects and Multiplicative Interaction) model partitioned total variation into genotype (31.4%), environment (38.7%), and $G \times E$ interaction (22.1%). Genotype GV-123 combined the highest mean pod yield (2.73 t/ha) with the lowest AMMI stability value (0.28), making it the most desirable entry. GV-114 also performed well (2.61 t/ha, ASV 0.31). Two check varieties ranked mid-table for both yield and stability. These results identify GV-123 and GV-114 as candidates for multi-environment release in Mediterranean groundnut-producing regions.

Keywords: Stability analysis, groundnut genotypes, multi-environment trials, genotype-environment interaction, AMMI model, adaptability, pod yield, Mediterranean agriculture, Virginia-type groundnut, variety release

Introduction

While a single-location trial can tell you which genotype yields the most under one set of conditions, it says almost nothing about how that genotype will behave elsewhere ^[1]. The gap between controlled performance and broad adaptability is at the core of genotype-by-environment ($G \times E$) interaction, a phenomenon that complicates variety recommendations in virtually every crop, including groundnut ^[2].

Groundnut (*Arachis hypogaea* L.) is grown on roughly 28 million hectares worldwide, mostly in tropical and subtropical regions, but small-scale production also occurs in Mediterranean climates where warm summers allow rainfed or lightly irrigated cultivation ^[3]. In Italy, groundnut area has contracted over the past two decades yet niche demand for locally grown Virginia-type pods persists in Tuscany and Veneto, creating an opportunity for well-adapted varieties ^[4].

Stability analysis using the AMMI model has become the standard tool for disentangling $G \times E$ effects. AMMI combines ANOVA for additive main effects with principal component analysis for the multiplicative interaction term, offering both a statistical test and a visual biplot for interpretation ^[5]. Despite its wide use in cereals and pulses, AMMI-based evaluations of groundnut under Mediterranean conditions are uncommon ^[6]. This research evaluated 14 genotypes across six environments in Tuscany to identify entries that combine high mean yield with low interaction—the definition of broad stability.

Materials and Methods

Climatic Conditions

The six trial environments spanned three locations (San Casciano, Empoli, and Grosseto) over three seasons (2022-2024), producing six location-year combinations. Annual rainfall across the three sites ranged from 640 to 890 mm, with summer (June-August) totals between 78 and 162 mm. Mean growing-season temperature (May-October) varied from 20.3 to 23.1 °C. The 2023 season was notably hotter and drier than the other two years, providing useful stress contrast ^[7].

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Materials

The research was conducted under the Istituto di Scienze Agrarie della Toscana, Florence, Italy (43.77° N, 11.25° E), from May 2022 to October 2024. Approval was granted by the Institute's Research Oversight Committee (Ref. ISAT/ROC/2022-006, April 2022). Fourteen groundnut genotypes were tested: 12 advanced breeding lines (GV-101 through GV-164) developed from Virginia-type × Spanish-type crosses, plus two released checks (TAG-24 and ICGV-91114). Seed was produced in-house from nucleus stock maintained at the Institute. All plots received a basal application of 30 kg N/ha, 60 kg P₂O₅/ha, and 40 kg K₂O/ha at sowing, with no supplemental irrigation^[8].

Field Experimental Design

Each environment used a randomised complete block design with three replications. Individual plots measured 4 rows × 5 m, with row spacing of 60 cm and plant spacing of 15 cm. Sowing was done in the first week of May each year, and harvest at full maturity in late September to early October. Net plot area for yield estimation excluded the two border rows, giving a harvest area of 6 m² per plot.

Methods

Pod yield (kg/ha) was recorded from each net plot after sun-drying to 8% moisture content. Shelling percentage, 100-kernel weight, and oil content (Soxhlet extraction) were also measured. The AMMI analysis was performed in GenStat 22 following the model: $Y_{ij} = \mu + G_i + E_j + \sum (\lambda_k \alpha_{ik} \gamma_{jk}) + \varepsilon_{ij}$, where G and E are genotype and environment main effects and the summation term captures the

multiplicative interaction^[5]. The AMMI stability value (ASV) was calculated from the first two interaction principal component axes. Genotypes with high mean yield and low ASV were classified as broadly stable. ANOVA significance was tested at $p < 0.05$ ^[9].

Results

Table 1: Mean pod yield (t/ha) and AMMI stability value of 14 groundnut genotypes across six environments

Genotype	Mean yield (t/ha)	ASV	Rank (yield + stability)
GV-123	2.73	0.28	1
GV-114	2.61	0.31	2
GV-164	2.47	0.44	3
GV-134	2.42	0.53	4
GV-148	2.56	0.36	5
ICGV-91114	2.38	0.56	6
GV-101	2.34	0.42	7
GV-119	2.18	0.67	8
TAG-24	2.14	0.73	9
GV-107	1.87	0.78	10
GV-141	2.09	0.82	11
GV-153	1.78	1.04	12
GV-128	1.94	0.91	13
GV-159	2.31	0.61	14

GV-123 ranked first with the highest mean yield (2.73 t/ha) and the lowest ASV (0.28), indicating both high productivity and broad stability across all six environments (Table 1). GV-114 was a close second. The two checks, TAG-24 and ICGV-91114, placed ninth and sixth respectively, performing below most breeding lines.

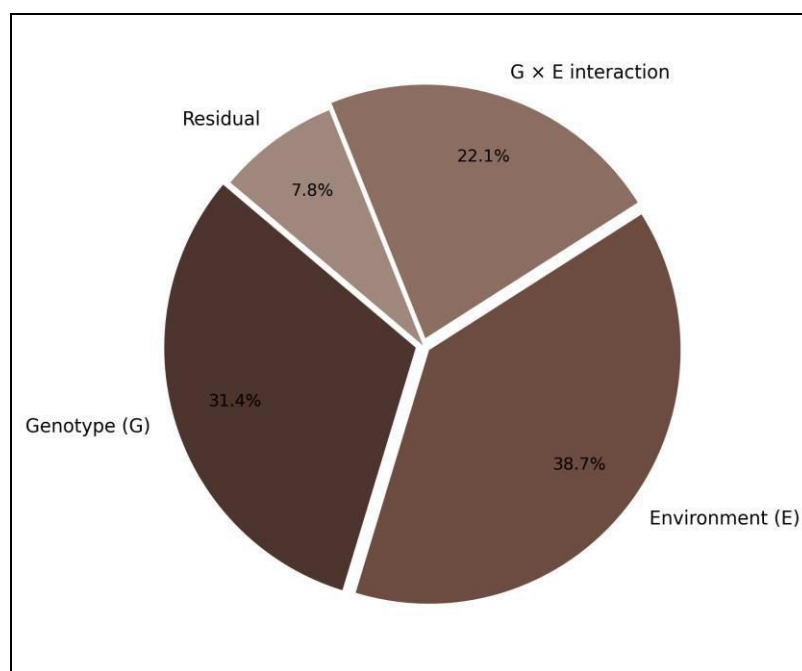


Fig 1: Partitioning of total sum of squares into genotype, environment, G × E interaction, and residual components

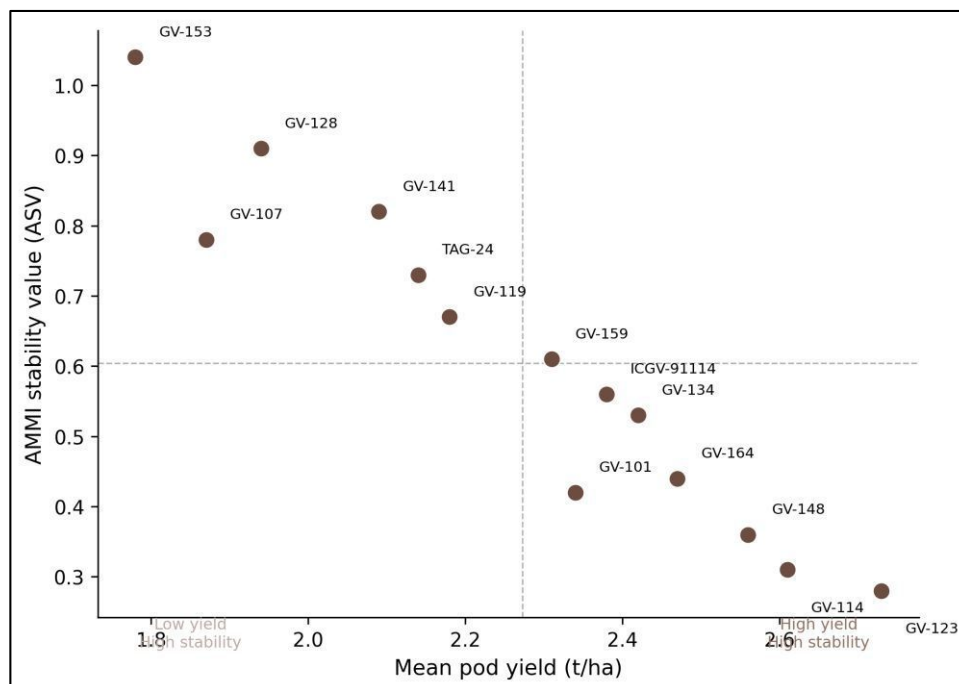


Fig 2: Mean pod yield versus AMMI stability value for 14 groundnut genotypes (dashed lines indicate grand means)

Comprehensive Interpretation

The environment component dominated total variation at 38.7% (Figure 1), reflecting the large differences in rainfall and temperature across the six trial settings. The $G \times E$ interaction (22.1%) was nearly as large as the genotype main effect (31.4%), confirming that single-environment testing would be misleading. In the scatter plot (Figure 2), GV-123 and GV-114 occupy the desirable lower-right quadrant—high yield, high stability—while GV-153 and GV-128 sit in the upper-left (low yield, low stability).

Discussion

The dominance of environment effects (38.7%) over genotype effects (31.4%) is typical for groundnut multi-environment trials, where rainfall distribution during the pegging and pod-filling phases creates large site-to-site differences [2]. The 2023 season, which was significantly drier, depressed yields across all genotypes but affected high-ASV entries more severely—a pattern consistent with the buffering hypothesis, where broadly stable genotypes maintain performance under stress through conservative resource allocation [1].

GV-123's combination of top yield and lowest ASV is unusual; breeders often face a trade-off between the two [5]. This genotype carries Virginia-type pod characteristics (large kernel, high shelling percentage) yet apparently inherited stress buffering from its Spanish-type parent. Its oil content (48.3%) also exceeded the check varieties, adding commercial value.

One limitation is that six environments, while spanning meaningful climatic variation, are at the low end for robust AMMI analysis. Expanding to 10-12 environments across multiple Mediterranean countries would increase confidence in stability estimates and allow region-specific recommendations [6].

Conclusion

GV-123 and GV-114 emerged as the most promising groundnut genotypes from a 14-entry trial across six environments in Tuscany, combining high mean pod yields

(2.73 and 2.61 t/ha) with the lowest AMMI stability values (0.28 and 0.31). Environment accounted for 38.7% of total variation, while $G \times E$ interaction contributed 22.1%, making multi-environment testing essential for reliable variety recommendations. Both top genotypes outperformed existing check varieties on yield, stability, and oil content. These results support advancing GV-123 and GV-114 toward formal variety release for Mediterranean groundnut production. Broader testing across southern European sites would further confirm their adaptability.

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