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Review of the Doctoral Dissertation by Abu Zar Ghafoor
Title: *Evaluation of genotype × environment interaction for grain crop quality*

The concept of trait stability and genotype × environment (G×E) interaction has long been the focus of extensive scientific research. Over the years, a broad analytical framework has been developed, ranging from univariate methods (e.g., Shukla's mixed model and the joint regression model of Eberhart-Russell-Shukla; Scheffé-Caliński mixed model and Caliński-Kaczmarek joint regression model) to multivariate approaches (e.g., AMMI, GGE), as well as various measures of adaptability (such as yield superiority index, cultivar superiority measure, and Kang's yield stability index). Recently, the field has expanded considerably by applying multivariate approaches, including classical statistical methods and machine learning techniques. Despite the decades of research already devoted to trait stability in plants, the subject remains highly relevant today, due to the constant Introduction of new cultivars, the development of novel methods for assessing G×E interactions, and the growing demand among plant breeders for practical tools and methodologies to evaluate genotypes in breeding programs.

The dissertation under review addresses this topic precisely, employing multivariate methods to assess stability while presenting new and original findings on the stability of spring wheat, winter wheat, and winter rye. This subject is significant and crucial for advancing scientific understanding and has profound practical implications for crop breeding, particularly cereal breeding.

The dissertation consists of three scientific papers published in peer-reviewed journals – *Agriculture* (Multidisciplinary Digital Publishing Institute), *Agronomy* (Multidisciplinary Digital Publishing Institute), and *Agronomy Journal* (American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America). These publications are supplemented with a descriptive part summarizing the most important results and conclusions derived from the research.

Formal Assessment

The The dissertation comprises three peer-reviewed publications:

1. **Abu Zar Ghafoor**, Alicja Ceglińska, Hassan Karim, Magdalena Wijata, Grzegorz Sobczyński, Adriana Derejko, Marcin Studnicki, Jan Rozbicki, and Grażyna Cacak-Pietrzak. *Influence of Genotype, Environment, and Crop Management on the Yield and Bread-Making Quality in Spring Wheat Cultivars*. *Agriculture*, 2024, 14(12), 2131. https://doi.org/10.3390/agriculture14122131 (IF = 3.3; 100 points).
2. **Abu Zar Ghafoor**, Adriana Derejko, and Marcin Studnicki. *Identification of Plant and Soil Characteristics Affecting Stability of Winter Wheat Cultivar in Temperate Climates*. *Agronomy*, 2024, 14(4), 779. https://doi.org/10.3390/agronomy14040779 (IF = 3.3; 100 points).
3. **Abu Zar Ghafoor**, Magdalena Wijata, Jan Rozbicki, Robert Krzysztofik, Kazimierz Banasik, Hassan Karim, Adriana Derejko, and Marcin Studnicki. *Influence of Crop Management on Stability of Rye Yield and Selected Grain Quality Traits*. *Agronomy Journal*, 2024, 1–12. https://doi.org/10.1002/agj2.21647 (IF = 2.0; 100 points).

In all three papers, the doctoral candidate takes the lead as the first author, with declared contributions of 70%, 85%, and 70% respectively. This clearly showcases the candidate's pivotal role in the research. The cumulative impact factor of these publications is 8.6, totaling 300 points according to the Polish Ministry of Science and Higher Education (MNiSW) system.

The descriptive part of the dissertation comprises 145 pages and is organized as follows:

- **Acknowledgments, Abstract** (in English and Polish)**, and List of Publications** (nine pages)
- **Chapter I – Introduction** (five pages)
- **Chapter II – Literature Review** (ten pages, including four figures)
- **Chapter III – Materials and Methods** (eight pages)
- **Chapter IV – Results** (26 pages, including nine tables and nine figures)
- **Chapter V – Discussion** (seven pages)
- **Chapter VI – Conclusions** (three pages)
- **References, Supplementary Materials, Author's Resume, and Appendices** (79 pages, including eight supplementary tables and reprints of the three publications).

This structure is appropriate for a doctoral dissertation.

The *Introduction* presents the research context, including climate change and cereal adaptation, the significance of multivariate methods in G×E interaction analysis, and the primary and specific research objectives and hypotheses.

The *Literature Review* discusses the current state of knowledge on G×E interaction and trait stability, the concept of multi-trait stability, and analytical tools applied in the

stability assessment of wheat and rye. It identifies research gaps, particularly in multivariate analyses of these crops.

The *Materials and Methods* chapter describes the experimental material: multi-environment trials for spring wheat (cultivars: Bombona, Izera, Torridon, Ostka Smolicka, Radocha, Trappe, Tybalt); trials conducted within the official variety testing system (COBORU) for winter wheat; and two-year, multi-location trials for rye (11 populations and 5 F1 hybrid cultivars from European breeding programs). The analytical approaches included linear mixed models, canonical correspondence analysis, classification and regression trees (CART), Shukla's stability variance, and the Multi-trait Stability Index (MTSI).

The *Results* and *Discussion* chapters present and critically interpret the main findings, followed by concise *Conclusions*.

The bibliography includes 52 references, over 90% published in the last decade. The dissertation is written in clear and correct language. Minor editorial shortcomings (e.g., occasional inconsistencies in page numbering in the table of contents) do not affect the substantive quality of the work.

Substantive Assessment

The general and specific research objectives are clearly stated, and the hypotheses are well formulated.

The experimental material is broad in scope, encompassing multi-environment comparative trials and post-registration variety testing (COBORU). The focus crops – winter wheat, spring wheat, and winter rye – are of significant agricultural importance in temperate regions. The candidate demonstrated strong competence in selecting relevant material and a sound awareness of current challenges in global agriculture. Importantly, the experimental design was described and analyzed with due attention to detail.

The range of analytical methods employed by the candidate is impressively broad. Beyond linear mixed models, canonical correspondence analysis, and CART, the candidate also applied principal component analysis (PCA), path coefficient analysis/structural equation modeling (SEM), and correlation measures (Pearson and Spearman). Together with Shukla's stability variance and the MTSI index, these analyses provided a robust methodological foundation. All analyses used R, reflecting the candidate's strong command of statistical and multivariate techniques.

In areas beyond his core expertise, the candidate did not just seek help but actively collaborated with specialists in food technology, agronomy, plant pathology, and cereal breeding, illustrating his openness and eagerness for interdisciplinary cooperation.

The discussion of results is not just thorough but also insightful and comprehensive. A key contribution was disentangling environmental effects (location, weather) from agronomic management effects. Notably, while previous studies emphasized the dominance of environmental factors, the multivariate approach demonstrated that crop management accounted for approximately 25% of yield variation. This highlights the candidate's ability to evaluate and situate his results in the broader literature critically.

Overall, the candidate has demonstrated excellent preparation for independent research, fully meeting the expectations of doctoral-level scholarship in applied sciences. The dissertation findings are valuable not only for agronomists and cereal growers, but above all for plant breeders, as they underscore the necessity of incorporating multivariate approaches into G×E analysis to enhance the efficiency of breeding programs.

One remark concerns the conceptual framework of stability. For decades, Becker and Léon's (1988) distinction between agricultural stability (traits change proportionally to the environment) and biological stability (traits remain unchanged regardless of environment) has been considered fundamental. It would be interesting to know whether and how the multivariate approaches applied here address or refine this dual perspective.

I also welcome clarification on the validation of the CART model. While validation relies on formal statistical tests in statistical modeling, data analysis, and machine learning methods require alternative approaches, such as cross-validation, Bayesian techniques (phylogenetic trees), or similar.

Conclusion

The dissertation **meets all requirements** specified in Article 187 of the *Act on Higher Education and Science* of 20 July 2018 (consolidated text: Dz.U. 2023, item 742, as amended).

Mr. Abu Zar Ghafoor has demonstrated independence in conducting scientific research, the ability to select appropriate experimental material, strong methodological competence in data analysis (including statistical and multivariate approaches), openness to collaboration, a thorough and detailed approach to analyzing results, critical thinking skills, and the capacity for scientific synthesis. Notably, all three publications included in the dissertation were published within a single year (2024).

I therefore recommend to the **Discipline Council of Agriculture and Horticulture at the Warsaw University of Life Sciences** that Mr. Abu Zar Ghafoor be admitted to the subsequent stages of the doctoral degree procedure.

Podpisano przez/ Signed by:
Dariusz
Mańkowski
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