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Hans H. Ruthenberg Award for Graduates 2024

Anna Tabea Mengen “Assessing Genotype by Environment Interactions and farmers' preferences in participatory maize selection in eastern Zambia and implications for the breeding process”, University of Hohenheim, 2023

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Summary

One of the greatest global challenges is providing the growing world population with sufficient and nutritious food, particularly in the face of climate change and land degradation. Countries of the global south, where smallholder farmers make up the majority of the agricultural workforce, are particularly affected. Crop yields in Sub-Saharan Africa (SSA) have remained stagnant, directly impacting peoples' livelihoods in this region. In Zambia, maize is the most important staple crop, cultivated by most smallholder farmers and subject to important governmental agricultural policies. Developing improved crop varieties through plant breeding is a key lever to increase agricultural production and resilience. However, formal plant breeding approaches have had limited success in addressing the specific needs and realities of smallholder farmers in SSA. Participatory plant breeding (PPB) has been proposed as an alternative approach, which involves farmers in the selection process to better meet their specific needs and preferences. This master's thesis was conducted in the context of the "Seeds for Zambian Incomes and Livelihoods" participatory breeding project, which aims to support Zambian smallholder farmers to produce according to their specific needs, thereby enhancing food security, incomes, and livelihoods.

The first objective of this thesis is to understand Zambian smallholder farmers' decision criteria for selecting maize cultivars and the diversity of their preferences based on social, economic, and environmental factors. The second objective is to assess the effects and causes of genotype-by-environment interaction (GEI) regarding variety performance and farmer appreciation, as well as differences in on-farm and on-station trials. Finally, recommendations to improve the efficiency of participatory breeding processes and generate suitable maize cultivars for eastern Zambia are developed.

The study was conducted during the 2021/22 cropping season and comprised participatory variety trials on smallholder farmers' fields in the Eastern province of Zambia, as well as on-station variety testing on a test station near Chipata. The on-farm trials tested 22 officially released maize varieties, along with 2 check varieties, using an alpha-lattice design, with farmers managing the trials under their usual cropping practices and scoring various agronomic and quality traits through visual observation, most importantly overall appreciation of a variety. Yield was assessed metrically. Separate group scoring sessions were also held with

20-40 local farmers per trial to assess their variety preferences. The on-station trials evaluated 23 officially released maize varieties, including 21 from the on-farm trials, under different nitrogen levels, using an alpha-lattice design, with group scoring sessions conducted as well. The data from these on-farm and on-station trials was analyzed using a multi-pronged statistical approach, including single location analysis to assess trait repeatability and correlations, additive main effects and multiplicative interactions (AMMI) analysis to explore GEI for yield and variety appreciation, correlation of AMMI principal component scores with environmental and genotypic factors, mixed models to quantify the influence of various environmental factors on GEI, and comparison of on-farm and on-station results for yield and farmer preference scores.

The single-location analysis of the on-farm trials revealed variable data quality, with metric traits generally showing high repeatability, while scored traits had more variable repeatability. Correlations between different agronomic and quality traits were moderate, with the strongest links being between variety appreciation and yield-related traits like cob number, cob size, as well as grain characteristics. Correlations of trait performance between trial locations were generally positive for yield, but more variable for variety appreciation, indicating differences in farmer preferences across locations. The AMMI analysis found significant genotype, environment, and GEI effects for both yield and variety appreciation. For yield, the environment explained the largest portion of variance, while for global appreciation, GEI was the dominant factor; as confirmed by the mixed models analysis. AMMI biplots revealed groupings of trial locations based on yield levels, as well as differences in farmer preferences across locations. Correlations of AMMI principal component scores with environmental and genotypic factors provided insights into the sources of GEI, with yield GEI being impacted by factors related to crop management, such as timing and type of weeding and fertilization, as well as farmer age, but giving lesser indication than expected. Variety appreciation GEI was more influenced by yield, followed by similar factors as above. Overall, farmers preferred hybrids over open-pollinated varieties. Quantification of the influential factors of GEI using mixed models overall showed the same picture, but additionally suggested farmer gender influenced yield GEI. The comparison of on-farm and on-station trial results showed generally positive, but variable, rank correlations of genotype performance. On-station trials had higher mean yields compared to on-farm trials, but the preference scores of many on-farm locations showed the highest correlations with the on-station trial with a higher fertilization level. Male and female farmer groups showed rather similar variety preferences.

While yield remains paramount, farmers also assess varieties based on a broader set of characteristics, including cob size, grain quality, and resistance to pests, diseases, and lodging. The individual focus of those varies between farmers, reflecting diverse farmer needs and underscoring the importance of considering a wider array of traits in breeding programs. Drought tolerance and early maturity were less important than expected, indicating already sufficient adaptedness of varieties to the local climate. Whether preference for hybrid varieties would translate to seed requests without government subsidies has to be investigated further. The results regarding factors influencing GEI of yield and farmers' appreciation of a variety point towards a complex interaction between socioeconomic variables, such as gender, age and wealth, and biophysical variables, such as soil quality and management choices, of a farmer's context. To assess the dimensions relevant to inform breeding programs, more intersectional approaches will be necessary to represent farmers' contexts. The maize varieties tested here appear to be sufficiently adapted to the trial area and find farmers approval. This indicates the required variation in cultivar characteristics is low, which should be validated by further trials in coming seasons in order to define maize breeding goals. An important question in designing

participatory breeding programs is the design of trials and the optimal mode of variety evaluation and farmer participation, which was found to be depending on a breeding programs goals. For a realistic yield prognosis, on-farm trials are necessary, as there is a considerable yield gap between both systems. On the other hand, yield rankings correlate well, and farmer group scorings agree with the on-station group scoring the most, indicating variety differences are better assessed in on-farm trials. Regarding farmer participation, group scorings generate feedback from and relevance to more farmers and increase participation, but only for a certain point in the growing season, while individual scorings by the plot manager allow horizontal observation throughout the season, more detailed scoring of several traits and information on the socio-ecological context, but only for one farmer. With limited resources, programs have to prioritize trial designs according to the research and breeding goals. Furthermore, on-farm trials may benefit from simplification of technical procedures and data quality will likely improve as limitations will be overcome and farmers and researchers learn from this experiment for following trial seasons. Complementing this study's data from one growing season with experiments on consumption-related traits, an improved set of socio-economic and bio-physical influential factors, and repeated multi-environment trials throughout the years will enable thorough analysis of and insights into local contexts and farmers needs for maize varieties.

Based on results and discussion, several recommendations for variety evaluation in the SeZIL project, specifically maize, and participatory maize breeding in eastern Zambia in general, were derived. For all recommendations to be meaningful, multi-year trials to validate findings are required. A baseline breeding programme can be developed, based on varieties and traits that performed well across trials. This can be complemented by programs for specific production objectives, based on more nuanced farmer feedback. In general, further research, as well as participatory breeding programs, have to take into account the whole product value chain, from cultivation to consumption. Regarding intersectional research approaches, field management aspects should be considered in the socio-economic context that determines them and potential (marginalized) target groups have to be identified in terms of intersectional status-groups, rather than fixed categories, such as gender. On-farm trials should be feasible and understandable for the farmer and measures to increase heritabilities have to be taken if trialing is to be moved from on-station to on-farm contexts. The mode of farmer participation has to be decided for each trial individually, according to the programs goals. Finally, all breeding programs are only successful, if varieties are adopted. Therefore, local governmental policies and their implications for farmer decisions always have to be kept in mind when designing participatory breeding programs. After all, this thesis shows how PPB is a valuable concept for integrating farmers perspectives and realities into plant breeding for eastern Zambia, with a range of options to fit the implementation to the requirements of a certain situation. This makes it an important tool for striving towards advances in food security for Zambian smallholder farmers by means of useful improved varieties and faster varietal turnover. This thesis lays the foundation for developing a participatory maize breeding programme for eastern Zambia and provides an overview of aspects to be picked up and investigated in more detail by further studies. Enabling meaningful focus of future research, it contributes to developing and applying strategies to improve food security and farmers' livelihoods.