

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important food crops in the world, serving as a major source of food, animal feed, and industrial raw materials, making a major contribution to global food security and the sustainability of agricultural systems. In 2022, global maize production exceeded 1 billion tonnes, making maize one of the cereals with the highest international production levels (Zhang *et al.*, 2024). Maize is not only consumed directly as a food ingredient but is also processed into various food products, such as flour and syrup, and is widely used as animal feed due to its high nutritional and energy content (Bharathi *et al.*, 2021). Furthermore, the role of maize in the animal feed supply chain contributes significantly to the production of animal protein, which is essential to meet the nutritional needs of the world's growing population (Tandzi & Mutengwa, 2020; G. Wang *et al.*, 2021) (Ali *et al.*, 2023). In the industrial sector, maize is used as a raw material for biofuels and various bio products, thereby increasing its economic value and its role in agricultural and industrial systems (Nwokoro *et al.*, 2022; Galindo *et al.*, 2024).

High production is one of the targets in developing superior maize varieties (Amzeri *et al.*, 2024; Amzeri *et al.*, 2024). However, the nutritional quality of maize kernels (especially kernel protein content) is a significant challenge in efforts to increase the nutritional value of food and feed. Some varieties of maize are reported to have protein content of around 9–10% in their kernels, which can improve the nutritional quality for humans and livestock (Kumar *et al.*, 2023). Efforts to increase maize protein content have been carried out through a targeted genetic approach, particularly to improve nitrogen utilization efficiency (Zhu *et al.*, 2025a). In addition to genetic factors, agronomic practices and environmental conditions also influence kernel protein accumulation, so the nutritional quality of maize can vary between locations and planting seasons. (L. Wang *et al.*, 2023).

The role of maize germplasm in improving agronomic traits and protein content is crucial to the development of superior maize varieties. Diverse germplasm offers a valuable genetic resource, allowing breeders to investigate variations in agronomic traits such as resistance to pests and diseases, as well as adaptability to extreme environmental conditions (Badu-Apraku *et al.*, 2021; Amzeri *et al.*, 2022). In addition, the research results showed that maize breeding that utilized germplasm as a source of genetic diversity has the potential to increase kernel protein content, driven by a strong association between genetic variation and nutritional traits (Li *et al.*, 2021a). The use of modern breeding techniques and genome-based approaches allows the detection of desirable traits in germplasm, including high protein levels, which are essential for increasing the nutritional value of maize as a food source and animal feed (Nie *et al.*, 2021). Utilizing this diversity means that breeding programs not only focus on increasing crop yields but also on improving nutritional quality, which is increasingly important amid the world's ever-increasing nutritional needs (Azmach *et al.*, 2021). Therefore, maize germplasm plays an important role in developing more adaptive and nutritious varieties, thereby supporting agricultural sustainability and food security.

The limitations of research evaluating agronomic traits and protein content in corn germplasm using multivariate analysis to identify variation patterns and potential breeding materials include several important aspects. Many studies are limited in the number of variables analyzed and thus do not fully capture the complexity of the interactions between agronomic traits and kernel protein content in maize (Favela *et al.*, 2021). High multicollinearity among independent variables can reduce model accuracy, leading to biased parameter estimates and incorrect interpretations of results (Gowda *et al.*, 2021a). In addition, data quality is often a challenge, where the collected data may not be representative of the existing germplasm diversity. This condition can result in a lack of generalization of the analysis results to broader field conditions (Badu-Apraku *et al.*, 2021; Rana *et al.*, 2024).

Methodological limitations also emerge when employing statistical techniques that depend on specific data distribution assumptions; if these assumptions are unmet, they may introduce bias into the analysis results (Ligeyo *et al.*, 2024). Furthermore, many studies have not accounted for environmental factors that can influence both agronomic traits and kernel protein content, such as climate differences, soil management, and fertilization type (Azmach *et al.*, 2021). Therefore, more integrated research that employs a multidimensional approach and considers environmental influences and interactions among factors is needed to provide a more comprehensive understanding of maize germplasm traits and their breeding potential. This research aimed to evaluate the relationship between quantitative agronomic traits and kernel protein content in 30 maize germplasm accessions, using descriptive and multivariate statistical approaches to identify the main traits contributing to increased kernel protein content.