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Potential for dual-purpose maize varieties to meet changing maize demands: Synthesis

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1. Introduction

Maize—or corn (*Zea mays* L.)—now is the most important global cereal in terms of production reflecting its versatility in use, including human food, animal feed and fodder, industrial products and biofuel. Most uses revolve around maize grain as the primary product, although whole plant utilization for silage is also common in industrialized agriculture (e.g. Klopfenstein et al., 2013). Despite being a versatile crop, maize production and maize breeding efforts over time have typically had a single-purpose orientation. For instance, maize breeding has focused on overcoming biotic and abiotic stresses so as to generate high yielding, stress-tolerant and widely-adapted maize varieties through judicious combination of conventional and molecular breeding approaches (Muttoni et al., 2013; Shiferaw et al., 2011). Even smallholders within mixed maize–livestock systems typically focus on maize grain yield (De Groote et al., 2013), with maize stover as additional byproduct and benefit. Although farmers may still try to increase fodder off-take, they still try to minimize maize grain yield loss (Byerlee et al., 1989; Lukuyu et al., 2013).

Critical to the development and acceptance of dual-purpose maize are the potential trade-offs between grain and fodder both in terms of quantity and quality. Single-purpose maize can focus on either grain *or* fodder, with grain reflecting partial utilization of maize biomass against potentially full (above ground) biomass utilization for fodder (as in case of silage). Dual-purpose maize focuses on both grain *and* fodder (particularly stover), and typically the full (above ground) biomass. Optimization for one trait (grain) is inherently easier than for two traits (grain and fodder), and may be pursued in instances where the fodder/stover value is negligible. However, the widespread use of maize stover suggests it indeed has value, although typically less than the maize grain. Given that both traits have value and improvement for each is likely subject to diminishing returns, dual-purpose breeding could potentially make economic sense. Furthermore, similar to many cereals, maize varieties appear to have a wide variety of (grain and stover) yields and stover quality, and most interestingly, there are prospects within the range of stover quality to increase fodder quality without compromising grain yield. It is this potential of dual-purpose varieties that has reignited research interest and some of the research underlying this special issue. Indeed, despite earlier skepticism only a decade ago, substantial progress has been made in developing dual-purpose maize options for both grain and fodder purposes as reflected in the papers contained in this special issue (Erenstein et al., 2013).

This paper synthesizes the key findings presented in 12 papers in this Special Issue around the potential for dual-purpose maize varieties to meet changing maize demands. We summarize the key findings around three thematic areas: (1) demand for dual-purpose maize cultivars and associated targeting domains; (2) quality traits, whole plant utilization and phenotyping; and (3) exploiting trait variation for maize improvement. In a final section we provide some of the lessons learned and guidance for further dual-purpose maize research and development (R&D).

2. Demand for dual-purpose maize cultivars and associated targeting domains

While plant breeders have the technical capability to alter maize plant characteristics, adoption of new technologies or varieties requires an understanding of farmers' preferences for crop characteristics. Issues of trade-offs for other values, such as soil improvement and fuel, market forces, disease resistance, and availability of alternative inexpensive feed resources affect farmers' willingness to accept new varieties with improved stover quantity and fodder quality.

Four papers discussed the potential demand for dual-purpose maize cultivars in North and Meso-America and Eastern and Southern Africa and the potential trade-offs in the use of maize plant parts for food, feed, fodder and soil improvements. Ways are discussed to better match specifically identified and desired traits to farming and production systems. System contexts are provided by agro-ecologies, cropping pattern, human and livestock densities, importance of livestock and alternative feed and fodder resources in the form of rangelands and common property resources to help delineate targeting domains for dual-purpose maize cultivars.

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For the United States of America (USA), Klopfenstein et al. (2013) review the history of maize (corn) use and the current conditions impacting both maize production and its use as livestock feed. Starting in the middle of the 20th century, plentiful maize grain was used increasingly as livestock feed. Changes in maize use for ethanol production have altered demands for grain and resulted in new by-products that provide valuable feed sources and that have been used to replace maize in livestock feeding in the U.S.A. Maize has been used as a roughage source in two primary ways in the U.S.A., either as silage or through use of the stover remaining after the grain harvest (used ex situ or in situ). Crop breeding strategies have primarily focused on grain but breeding programs specifically for silage also exist. Klopfenstein et al. do report on one study in which varietal differences in morphological traits are compared in stovers, which showed some variation. They also discuss the value of grazed maize stover as fodder for beef cattle and suggest that maize stover can be well utilized as a roughage source for both gestating cows and growing calves as long as adequate protein is provided to meet the needs of rumen microbes. Research is cited that shows gains of up to 1 kg/d for calves supplemented with up to 3.5 kg of distillers grains while grazing maize stalks. These authors also discuss research that indicates that allowing cattle to graze maize stover during winter does not affect subsequent maize grain yields.

Hellin et al. (2013) take us to Mexico, the centre of origin of maize and U.S.A.'s southern neighbour. They use farmer group/community surveys in three contrasting agro-ecologies (semi-arid, temperate highland and tropical sub-humid) to explore maize stover use. Mixed maize–livestock smallholder farming systems prevail, with maize grain produced for home consumption and the market and maize stover as an important by-product, primarily as feed. Although in situ grazing is found in all three study sites, it represented the bulk of stover use in only one site (with an estimated 70% of stover in the sub-humid tropics), with ex situ feed dominating in the other two sites (estimated >80%). Maize stover commercialization was limited and mainly restricted to households with no livestock and often within the immediate local context. They also explore potential trade-offs in stover use, particularly its use as feed against its potential use as mulch (soil cover) to manage soil health within the context of conservation agriculture. They report that farmers are generally hesitant to adopt conservation agricultural practices that require the retention of stover as mulch, as this competes with their livestock feed needs and purchased feed is expensive. The authors go on to explore a portfolio of options to reduce these trade-offs, including partial residue retention, cover and feed crops and sustainable intensification. Promising (Muttoni et al., 2013) but yet to be explored further in the context of Mexico, are investments in generating dual-purpose (grain-fodder) maize varieties.

De Groote et al. (2013) investigated the potential demand for dual purpose maize in Ethiopia and Tanzania using participatory rural appraisals, farm household surveys and formal farmer evaluations of maize varieties, the latter focusing on commercially available material that were planted side-by-side in trial sites in the study areas as purposively developed dual-purpose maize varieties are not yet on the market. They show that maize stover is an important element of livestock feed in all the study areas. Desirable traits farmers consistently mentioned were related to grain yield and pest resistance, ease of cooking and taste characteristics and stover yield and fodder quality. Analysis of adoption patterns of existing maize varieties by farm households shows that varieties that score well on feed characteristics have a higher probability of being adopted. The authors concluded that there is a demand for varieties with superior stover quantity and fodder quality as long as grain yield and consumer preferences were not compromised. They further hypothesise that such varieties have the potential to increase the productivity of maize-livestock systems and the income of these farmers, provided these varieties are taken up in the seed portfolio of the emerging seed sector in the sub-region.

Homann-Kee Tui et al. (2013) explored the use of a multi-level approach and associated data sources to assess the potential of dual-purpose maize cultivars in Southern Africa. The authors construct recommendation domains for dual-purpose maize using maize mega-environments and demand estimates derived from livestock and human population densities and potential feed supply, including biomass contributions from range and croplands. These estimates were subjected to ground truthing through survey data collected from 480 households in contrasting sites in Malawi, Mozambique and Zimbabwe. In addition the authors' reported on maize varieties, both landraces and advanced hybrids, for variations in grain and stover yield and fodder quality traits. Their study showed that where livestock densities were high and feed resources from rangeland limited, maize cultivars with superior stover yield and fodder quality can have substantial impact on livestock productivity. Stover with higher fodder quality could provide sufficient energy for providing livestock maintenance requirements and support about 200 gram of live weight gain daily. The authors further proposed an approach to target grain-fodder maize cultivars to demand domains for either stover quantity or stover fodder quality based on maize stover intake estimations derived from Ravi et al. (2013). Homann-Kee Tui et al. complement and build on Notenbaert et al. (2013) who focused on eastern Africa to develop similar demand domains for dual-purpose maize as part of an integrated targeting approach based on maize mega environments, livestock numbers, population densities and alternative feed resources.

Research such as that reported in these four papers reinforces the need to evaluate the specific contexts for technology adoption. For example maize improvement/cultivar choice can increase stover quantity, stover quality or perhaps both. It is important to realize that from a livestock nutrition viewpoint, an increase in stover quantity is only useful (unless making stover cheaper) if livestock can respond with increased intake, which is stover quality dependent.

3. Quality traits, whole plant utilization and phenotyping

Evaluating the nutritional fodder value for livestock *in vivo* can be a complex and time consuming process. Additionally, livestock may be fed complex diets in which feedstuffs impact the utilization of one another. Nutritionists have long worked on developing laboratory indicators that well reflect animal response. Validation of rapid laboratory measures is key to evaluation of large collections of germplasm for screening.

A set of four papers looked into the variations in grain and stover traits in existing maize cultivars, their meaning for whole maize plant optimization, and laboratory phenotyping capability. These papers thus investigated exploitable variations in a range of food-feed-fodder traits in existing and widely used cultivars, the implication of these traits for livestock productivity and/or tradability of maize stover, and techniques for selecting and predicting specific traits.

Anandan et al. (2013) investigated six maize hybrids commonly grown in South Asia for grain and stover yields and for stover morphological (residual green leaf area, plant height, stem diameter and proportions of leaf blade: leaf sheath: stem), chemical (nitrogen (N), neutral (NDF) and acid (ADF) detergent fiber, acid detergent lignin (ADL)) and biological (in vitro organic matter digestibility (IVOMD) and metabolizable energy (ME) content) fodder quality traits. The stovers were also fed to sheep as major part (90%) of their feed. The authors observed significant cultivar differences