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Variations in food-fodder traits of bread wheat cultivars released for the Ethiopian highlands

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ABSTRACT

Twenty-five bread wheat varieties, developed for and released in the Ethiopian highlands, were investigated for grain (GY) and straw (SY) yields and straw fodder quality traits across two locations (Debre Zeit and Kulumsa) during 2016. Five varieties were selected for further investigation in 2017 at four locations representing a broader range of agroecologies. Straw fodder quality traits investigated were nitrogen (N), neutral detergent (NDF) and acid detergent fiber (ADF), acid detergent lignin (ADL), *in vitro* organic matter digestibility (IVOMD), and metabolizable energy (ME). In 2016, significant varietal differences ($P < 0.001$) were observed across locations for GY and SY, with GY ranging from 3.5 to 5.4 t ha^{-1} ($\bar{x} = 4.3 \pm 0.24$ t ha^{-1}) and SY ranging from 6.6 to 14.6 t ha^{-1} ($\bar{x} = 8.5 \pm 0.20$ t ha^{-1}). Varietal differences across locations were observed for NDF (74.6–78.0%; $P < 0.01$), ADF (48.5–52.3%, $P < 0.001$), and ADL (5.9–6.7%, $P < 0.0001$). The location effect was significant ($P < 0001$) for GY and SY and all straw fodder quality traits, with significant variety by location interaction for GY. The GY and SY in Kulumsa were 2.5 and 1.7-fold higher than the GY and SY in Debre Zeit, respectively. Straw quality traits were superior ($P < 0.05$) in Debre Zeit compared to Kulumsa, but differences in quality were proportionally smaller than the differences in the yields. Within Debre Zeit, significant varietal differences were found for GY ($P < 0.0001$) and ADL ($P < 0.01$), and a trend was observed for SY ($P = 0.06$). Within Kulumsa, significant varietal differences were found for GY ($P < 0.0001$), SY ($P < 0.0001$), and cell wall constituents ($P < 0.05$). A trend was observed for N content ($P = 0.07$). There was a weak positive relationship between GY and SY ($r = 0.35$, $P = 0.08$) across the locations. Grain yield was inversely related to N content of the straw ($r = -0.45$, $P = 0.02$), but the relationship with the other fodder quality traits was not significant. No significant relationship was found between SY and fodder quality traits. In 2017, the five varieties differed significantly ($P < 0.01$) both in yield and fodder quality traits with the exception of ME ($P = 0.59$). There was also significant ($P < 0.01$) variety by location interaction for N, and cell wall constituents, in addition to GY. Overall, GY and SY differences among bread wheat varieties were more substantial than differences in straw fodder traits and a fair amount of elasticity exists between yields and straw quality traits that can be exploited.

1. Introduction

Mixed crop livestock farming is the dominant production system in the highlands of Ethiopia. In this system, crop production and livestock rearing complement each other, with the former providing fodder in the form of crop residues and the latter serving as the main source of farm power, manure, and cash income for agricultural inputs. In the highlands, grazing lands have been declining and farmers increasingly depend on crop residues as a source of fodder (Duncan et al., 2016). Wheat is the most widely grown cereal in Ethiopia after tef (*Eragrostis tef*) and maize, and is cultivated annually on more than 1.6×10^6 ha of land, and producing an estimated 6.9×10^7 tons of straw dry matter (CSA, 2015). The majority of the wheat straw produced is used on farm as fodder but when sold in local fodder markets, prices for straw range from 50 to 60% that of the grain (Gebremedhin et al., 2009). As a result, the quantity of straw produced is important to smallholders, and

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Table 1
Altitude, soil type and climatic variables of the study sites.

Site	Altitude (m a.s.l.)	Representing agro-ecology	Soil type	Rainfall (mm)	Temperature (°C)	
					Minimum	Maximum
Debre Zeit	1925	Mid-altitude	Eutric vertisol	851	11.4	26.3
Kulumsa	2200	Mid-altitude	Clay loam (luvisol)	820	10.5	22.8
Asasa	2340	Terminal drought prone	Clay loam (gleysols)	620	5.8	23.6
Bekoji	2780	Highland/high rainfall	Clay (nitosols)	1020	7.9	18.6
Dawabusa	2990	Extremely highland and frost prone	Clay (nitosols)	1196	5.7	18.1

this often influences farmers' choice of variety (Bishawa and Alemu, 2017). Farmers often face short supply of wheat straw and other residues to feed livestock to appetite (*ad libitum*), which makes increasing the quality of the straw biomass very important.

In addition to increasing the quantity, improving the fodder quality of the straw is essential for smallholders to get optimal livestock output. Although several bread wheat cultivars have been developed for and released in the Ethiopian highlands, varietal differences in their food-fodder traits have largely been ignored. The present study therefore examines the presence and extent of genotypic variation in food-fodder traits of released bread wheat cultivars and investigates the potential trade-offs between food and fodder traits.

2. Materials and methods

2.1. Study site

The study was conducted during the main rainy season of 2016 and 2017 in the central highlands of Ethiopia. The first trial in 2016 was conducted in Debre Zeit and Kulumsa whereas the follow up trial in 2017 was conducted in Kulumsa, Asasa, Bekoji, and Dawabusa. The sites represent very diverse agro-ecologies for wheat, ranging from frost-prone (Dawabusa) to terminal drought-prone areas (Asasa). The agro-ecological description of the respective sites is reported in Table 1.

2.2. Experimental design

In 2016, twenty-five bread wheat cultivars developed and released for Ethiopia by the Ethiopian Institute of Agricultural Research (EIAR) were investigated for cultivar differences in food-feed traits at Debre Zeit and Kulumsa. The trial was a randomized complete block design with three replications. Seventy-five experimental plots, each of 1.2 m × 2.5 m, were used and the wheat cultivars were row planted (20 cm between rows) using a seed rate of 150 kg/ha and a fertilizer application of 200 kg urea and 100 kg di-ammonium phosphate per hectare. Upon reaching full maturity, each plot was harvested, sun dried and separated into grain and straw with their weights recorded. Representative grain samples were taken for dry matter (DM) determination and straw samples taken for DM and fodder quality analysis.

The trial was repeated in 2017 with five out of the 25 wheat cultivars sown in four locations with contrasting agro-ecologies (Kulumsa, Asasa, Bekoji, and Dawabusa). The five varieties used in the second trial (Hidasse, Kingbird, Ogolcho, Shorima, and Tay) were selected for their wide environmental adaptabilities and growing niches. The experimental procedures followed in the second trial were as described above.

2.3. Straw fodder quality analysis

The straw samples were dried at 65 °C in a forced air oven for 48 h, weighed and ground to pass through a 1 mm sieve. Near Infrared Spectroscopy (NIRS) was employed using equations calibrated and validated for a wide range of wheat straws. The NIRS instrument used was a FOSS Forage Analyzer 5000 with software package WinISI II. Predicted traits were straw nitrogen (N) (Crude protein = N*6.25), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), *in vitro* organic matter digestibility (IVOMD), and metabolizable energy (ME).

2.4. Statistical analysis

Analysis of variance was conducted using the General Linear Models procedure of SAS, by location and across location. Similarly, Pearson's correlation analyses were performed by location and across location. Regression analysis was conducted to further examine relationships between fodder quality and yield traits.

3. Results

3.1. Observations on food and fodder traits of twenty-five bread wheat cultivars in the first trial

3.1.1. Grain (GY) and straw yield (SY)

The yield and fodder quality variables of the 25 bread wheat cultivars investigated in 2016 are presented in Table 2. Varietal differences ($P < 0.001$) were found for GY and SY across the two locations (Debre Zeit and Kulumsa). The difference between low- and high-yielding varieties was approximately 1.5-fold for GY and 2.2-fold for SY. The yield variables were affected ($P < 0.001$) by location with the mean GY and SY in Kulumsa being 2.5-fold and 1.7-fold higher, respectively, than in Debre Zeit (Table 3). In Debre Zeit, the difference between low and high yielding varieties was approximately three-fold ($P < 0.001$) for GY and 1.6-fold ($P = 0.06$) for SY. In Kulumsa the varietal differences were two-fold ($P < 0.001$) and 1.7-fold ($P < 0.001$) for GY and SY, respectively. There was variety by location interaction effect ($P < 0.001$) for GY but not for SY ($P = 0.16$).

3.1.2. Straw fodder quality traits

Varietal differences in straw fodder quality traits among the 25 cultivars were observed ($P < 0.01$) across the two locations only for the cell wall constituents (NDF, ADF and ADL). There was location effect ($P < 0.001$) for all fodder quality traits, with mean straw quality traits in Debre Zeit superior to that in Kulumsa. The difference in fodder quality traits between the two locations were 1.5-fold for N, 1.1-fold for NDF and ADF, 1.2-fold for ADL and 1.1-fold for IVOMD. Within Debre Zeit only ADL varied ($P < 0.01$) among varieties. There was no location by variety interaction with regard to all of the fodder quality traits examined.

3.1.3. Relationship between straw fodder quality traits and GY and SY

Across the two locations a weak ($r = 0.35$, $P = 0.08$) positive association between GY and SY was observed (Table 4). Grain yield was inversely related to N content of the straw ($r = -0.45$, $P = 0.02$) but cell wall constituents, IVOMD and ME content were not significantly related to GY. Relationships between SY and straw quality traits were not significant. Within Debre Zeit GY and SY were weakly ($r = 0.22$, $P = 0.06$) positively correlated (Fig. 1). Grain yield was positively correlated with NDF ($r = 0.65$, $P < 0.001$), ADF ($r = 0.82$,