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Quantifying variations in rhizosheath and root system phenotypes of landraces and improved varieties of juvenile maize

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ABSTRACT

Rhizosheath and root system architecture (RSA) traits can provide insights into the capacity of a crop to exploit and acquire resources from the soil. This paper employed a rapid but simple screening and phenotyping approach to quantify the differences between selected maize landraces and improved varieties in terms of their rhizosheath and RSA characteristics at the seedling stage. Five maize landraces and thirteen improved varieties (eleven open-pollinated varieties and two hybrids, released in Ghana over the period 1984–2012) were used. Seeds were sown in nursery polybags, with two watering regimes (30% and 70% field capacity). Harvesting and screening for rhizosheath and RSA characteristics were done 7 days after sowing. The results showed that the improved varieties have superior RSA and rhizosheath characteristics compared to the landraces. The improved varieties were superior in shoot biomass, total root length, number of seminal roots, root hair length, and rhizosheath mass. The landraces were superior in terms of root hair density and root biomass. The improved varieties have similar RSA and rhizosheath characteristics independent of the era or period of release. Whilst rhizosheaths were partly explained by either root hair length or root hair density, denser root hairs seemed to compensate for shorter root hair in some genotypes. It is concluded that, at the juvenile stage, landraces and improved varieties of maize have significantly different rhizosheath and RSA characteristics. Yield advantages of improved varieties over that of locally cultivated maize landraces could be attributed to superior RSA and rhizosheath traits of the improved maize varieties. The approach adopted in this study can be useful for rapidly screening cereals at the juvenile stage for their RSA and rhizosheath characteristics.

1. Introduction

Root system architecture describes the organization, length/biomass quotient and the three dimensional distribution of the primary and lateral roots, as well as other accessory roots in the soil (Smith and De Smet, 2012; Ning et al., 2012, Lynch, 1995). On a microscale, RSA also includes root hairs, the tubular-shaped outgrowths of root epidermis cells that increase the surface area and facilitate soil resource acquisition (Smith and De Smet 2012; Kwasniewski, et al., 2016).The production of root hairs is among the array of mechanisms used by plant roots to increase their access to resources and tolerance to abiotic stress (George et al., 2014; White et al., 2013a, 2013b). To this end, rhizosheath has become interesting subject of research. Rhizosheaths are soil particles, matted together on roots by the intertwining growth of prolific epidermal hairs produced by the roots (Bailey and Scholes, 1997). On excavation, rhizosheaths are the weight of persistent soil coating encasing the roots on which they occur (Bailey and Scholes, 1997; George et al., 2014). In cereals and grasses, root hairs are known to be important for the formation of rhizosheaths (Bailey and Scholes, 1997).

Rhizosheaths were originally thought to be the result of mycorrhizal associations but have now been shown to be related to many other root

Abbreviations: ANOVA, Analysis of Variance; ARW.g., Absolute Rhizosheath Weight; CRI, Crops Research Institute; CSIR, Council for Scientific and Industrial Research; DW(s), Dry Weight(s); FC, Field capacity; FW, Fresh Weight; l.s.d., Least Significant Difference; MDSR, Mean Diameter of Seminal Roots; MLSR, Mean Length of Seminal Roots; OPV(s), Open Pollinated Variety(ies); PCA, Principal component analysis; RDW, Root Dry Weight; RHD, Root Hair Density; RHL, Root Hair Length; RRFw, Fresh Weight of Roots with Rhizosheath; RSA, Root System Architecture; Rw, Rhizosheath Free Root Fresh Weight; SDW, Shoot Dry Weight; SRL, Seminal Root Length; SRsNo, Number of Seminal Roots; SRW.g.g., Specific Rhizosheath Weight (g g^{-1}); SRW.mg.cm., Specific Rhizosheath Weight (mg cm^{-1}); SSD, Sum of Squared Differences; TLRL, Total Lateral Roots Length; TLSR, Total Length of Seminal Roots; TRL, Total Root Length; UCC, University of Cape Coast

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Table 1
Five commonly grown maize landraces and thirteen improved maize varieties released since 1984 in Ghana used in this study.
Source: Catalogue of crop varieties released and registered in Ghana Vol. 1, 2015; DTMA, 2013; Morris et al., 1999.

Name of variety	Year of release	Special trait(S)/remarks	Grain colour/texture	Grain yield (t/ha)	Days to maturity
	Hybrids				
Mamaba	1996	Drought tolerance	White flint	6.0	110
CSIR-Enii-Pibi (Enibi)	2010	Drought tolerant	White flint	5.5	110
	Open Pollinated Varieties (OPVs)				
Aburotia	1984	Early-maturing	White dent	4.6	105
Okomasa	1988	Streak resistant	White dent	5.5	120
Obaatanpa	1992	Streak resistant and QPM[a]	White dent	4.6	105
Tintim	1992	Very good for domestic purposes		7.9	115
Dorke SR	1990	Streak resistant	White dent	3.8	95
Dodzi	1997	Extra early maturity, useful to break hunger gap before main harvest	White flint/dent	4.5[a]	85
CSIR-Akposoe	2007	Extra early maturity, QPM[a], breaks hunger gap before main harvest	White flint/dent	3.5	85
CSIR-Abontem	2010	Drought tolerant, striga resistant, QPM[a] and extra-early maturity	Yellow flint	4.7	80
CSIR-Aburohemaa	2010	Drought tolerant, striga resistant and QPM[a]	White flint	5.0	90
CSIR-Omankwa	2010	Drought tolerant, striga resistant, QPM[a]	White flint	5.0	90
Honampa	2012	Less pest attack on grains and contains7 μg/g provitamin A	Yellow	5.2	115
	Landraces				
Designation		**Region of collection**	**Grain colur**		
CY01		Central region		Yellow	
EW01		Eastern region		White	
EW03		Eastern region		White	
EY04		Eastern region		Yellow	
WR01		Western region		Red	

[a] QPM: Quality Protein Maize.

traits (George et al., 2014; Haling et al., 2010a, 2010b, 2014). The root traits to which rhizosheaths have been related include the lengths, density and morphology of root hairs (Haling et al., 2010b), and root and microbial mucilage (McCully, 1999). Rhizosheaths have also been related to soil water content (Watt et al., 1994), soil porosity and strength (Haling et al., 2014), microbial communities including free living bacteria and associative diazotrophs (Othman et al., 2004; Tahir et al., 2015; Unno et al., 2005). Larger rhizosheath mass (hence longer root hairs and/or a higher density of root hairs) has been shown to be very important for improving mineral uptake (especially phosphorus) and drought tolerance or plant-water relations (Brown et al., 2012; 2013; George et al., 2014; Kwasniewski et al., 2016; Haling et al., 2010a, 2010b; Young 1995; Watt et al., 1994). For example,in field trials, grain yields were lower in maize (*Zea mays* L.) mutants without root hairs than their wild counterparts and this may have been a consequence of altered uptake of water and nutrients (Hochholdinger et al., 2008). Rhizosheaths may protect the water status of young root tissue (Lynch et al., 2014). Rhizosheaths have also been associated with tolerance to hard soils and aluminium-induced soil acidity (Haling et al., 2010a, 2010b, 2013, 2014; Brown et al., 2012; Delhaize et al., 2012), as well as the mitigation of zinc deficiencies (Nambiar, 1976; Haling et al., 2013).

Maize is the most widely consumed staple food and the most widely cultivated food crop (covering approximately 1 million ha of land) in Ghana (DTMA, 2013; Morris et al., 1999). Breeding effort has been directed at bridging the yield gap through effective capture and efficient use of especially soil resources. Since 1983, over 40 maize varieties have been released in Ghana, including open pollinated varieties (OPVs) and hybrids (DTMA, 2013; Morris et al., 1999). However, a substantial number of Ghanaian farmers grow landraces. Due to their superior root system architecture (RSA) and ability to better acquire soil resources and withstand abiotic stresses, improved maize varieties have much higher grain yield than landraces (Ning et al., 2015). There is little information on the root system and rhizosheath characteristics of both improved maize varieties and landraces in Ghana. The objective of this paper was therefore to quantify the differences in RSA and rhizosheath characteristics of selected maize landraces, open pollinated varieties (OPVs) and hybrids; and to assess the relationship between soil water content and rhizosheath characteristics of juvenile maize.

2. Materials and methods

2.1. Soil and environmental conditions

Topsoil (0–15 cm depth) was collected from a site near the Teaching and Research Farm of the School of Agriculture, University of Cape Coast (UCC; 5.1155°N, 1.2909°W). The soil was a haplic acrisol, typical of arable soils of the coastal savanna agro-ecological zone. The soil was a sandy loam with a pH of 6.1 and had 2.2% organic carbon, 0.5% total nitrogen (N), 26.1 μg phosphorus (P) g^{-1} and cation exchange capacity (CEC) 6.1 centimoles of charge per kg soil ($cmol_c$ kg^{-1}) exchangeable potassium (K). Collected soils were mixed, air-dried and passed through a 2-mm sieve to remove coarse materials and vegetative matter. Nursery polybags (3600 cm^3) with drainage holes underneath were filled with the soil, tapped very gently to achieve a bulk density of approximately 1.1 g cm^{-3}. The nursery bags filled with the soil were kept in the open under a rain shelter at the Teaching and Research Farm of the School of Agriculture. Temperature and relative humidity at the experimental site ranged between approximately 24 °C to 32 °C and 60% to 80%, respectively. Day length ranges from approximately 11.30 to 12.40 hours while solar radiation ranges from 3151 kJ cm^{-2} day^{-1} to 3804 kJ cm^{-2} day^{-1}, respectively (Abbey and Oppong-Konadu, 1997).

2.2. Maize genetic material

Five (5) maize landraces, eleven (11) open-pollinated varieties (OPVs) and two (2) hybrids (Table 1) were used. The landraces were common farmers' varieties grown in three agro-ecological zones in Ghana: Eastern region (deciduous forest zone), Western region (rain-