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On-farm Performance and Farmers' Perceptions of *DroughtTEGO*-Climate-Smart Maize Hybrids in Kenya

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ABSTRACT

Maize (*Zea mays* L.) productivity in the sub-Saharan Africa is constrained by biotic and abiotic stresses that reduce yield. In the region, one of the most serious abiotic factor is frequent intermittent droughts, which has been attributed to climate change. The purpose of this paper was to use on-farm demonstration studies and farmer field days to demonstrate new drought mitigation technology and provide information on how small farmers can reduce yield losses. A total of 4814 demonstration plots of 39 *DroughtTEGO* maize hybrids and 19 commercial check hybrids were established in 17 counties across the low-to-mid-altitude maize-growing agroecologies of Kenya between 2015 and 2017. A total of 246 field-day workshops were conducted. Combined analyses across years and locations showed that top five *DroughtTEGO* hybrids increased maize yields 33 to 54% (5.5–6.3 Mg ha^{-1}) relative to conventional hybrids. The highest yield advantage of *DroughtTEGO* hybrids over commercial checks was observed in the drier lower eastern region in Kenya. Farmers particularly women, preferred the *DroughtTEGO* hybrids because of the stay-green character, whiteness of flour (milling quality), root lodging resistance, drought-tolerance and shelling percentage. Results from this study suggested that smallholder farmers can reduce the impact of drought by seeding drought-tolerant maize hybrids.

Core Ideas

- High yields and farmer-preferred traits determine adoption of new varieties.
- Conducting on-farm demonstrations can overcome adoption barriers.
- Planting of drought-tolerant hybrids mitigates drought stress for smallholder-farmers.

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Declining agricultural productivity in sub-Saharan Africa (SSA) has been attributed to frequent drought events and floods caused by climate change (Mendelsohn, 2008; Chavas et al., 2009; Schlenker and Lobell, 2010; Muller et al., 2011; Gohari et al.,2013; Dao et al., 2015). These climatic conditions adversely impact food availability, commodity prices, and farmer livelihoods (Ngingi, 2009; Ringler et al., 2010; Ibrahim et al., 2014).

Maize is a staple food crop in many developing countries (Shiferaw et al., 2011; De Groote et al., 2013) and a major staple and cash crop for more than 300 million smallholder farmers in SSA (Mathenge et al., 2014). Although maize is widely adapted to a wide range of climatic conditions (Ureta et al., 2013), yields in SSA range from 1.1 to 1.7 Mg ha^{-1} (Smale et al., 2011) which is much lower than the global average of 4.5 Mg ha^{-1} (Khonje et al., 2015; Whitfield et al., 2015). These low yields are attributed to biotic and abiotic stresses (Vivek et al., 2010; Aylward et al., 2015).

Maize cultivation in the developing world relies heavily on rainfall (Jones and Thornton, 2003; Shiferaw et al., 2011; Papanastassiou, 2012; Burleigh Dodds Science Publishing, 2017). Drought and heat stresses suppress maize productivity (Jaleel et al., 2009; Tai et al., 2011; Aslam et al., 2015) and can reduce yields up to 100% (Jones and Thornton, 2003). Other constraints limiting yields include pests and diseases (Shiferaw et al., 2011; Abera et al., 2013, Ndwiga et al., 2013; Nyaligwa et al., 2016); growing old hybrid varieties/landraces; poor agronomic practices (Shiferaw et al., 2011 Abera et al., 2013; Nyaligwa et al., 2016; Burleigh Dodds Science Publishing, 2017); and low soil fertility (Papanastassiou, 2012; Wambugu et al., 2012). Development of varieties that are resilient to biotic and abiotic stresses is a key strategy to mitigate constraints to maize production (Jones and Thornton, 2003; Shiferaw et al., 2011) and reduce the pressure to conversion of non-cultivated areas to annual crops (Jones and Thornton, 2003).

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† In loving memory–passed in June 2019.

Abbreviations: AATF, African Agricultural Technology Foundation; AEZ, agroecological zone; FAO, Food and Agriculture Organization; LRS, Long rainy season; RCBD, Randomized Incomplete Block Design; R4D, Research-for-Development; SRS, short rainy season; SSA, sub-Saharan Africa; WEMA, water efficient maize for Africa.

In Kenya, maize is a staple food crop with more than 90% of the population relying on it daily (Nyameino et al., 2003; Kirimi et al., 2011; USDA, 2016). About 1.6 million hectares are cultivated annually by smallholder farmers who contribute 75% of the total maize production (Guantai and Seward, 2010). Kenya's average national annual maize yield is relatively low and ranges from 1.5 to 1.8 Mg ha^{-1} (FAOSTAT, 2018). Kenya's low yields are produced in spite of large investments in breeding new hybrids. The reasons for low adoption rates of new hybrids were discussed by Wekesa et al. (2003) and Smale and Olwande (2011, 2014).

Maize production in Kenya is concentrated in the low- to medium-altitude maize-growing zones which account for approximately 1.11 million hectares, with an average productivity of 1.1 Mg ha^{-1} (Government of Kenya, 2010). Several *DroughtTEGO* hybrids were developed and released for low- to medium-altitude (1000–1600 m above sea level) geographies in Kenya, Uganda, Tanzania, Mozambique, and South Africa under the Water Efficient Maize for Africa (WEMA) Project (Oikeh et al., 2014; Beyene et al., 2016; 2017; Edge et al., 2018). As part of the WEMA Project, The African Agricultural Technology Foundation (AATF) introduced *DroughtTEGO* hybrids for commercialization in Kenya. Abate et al. (2017) reported that despite the release of several new maize varieties in SSA, the average age of the oldest released variety was 20 yr, while the newest was 7 yr. The lack of adoption of the new cultivars is attributed to lack of performance data under farmers' conditions and the lack of demand for the new hybrids. Incorporating farmer-desired traits in the breeding pipeline could assist in wider adoption of new maize hybrids. The objective of this study was, therefore, to evaluate on-farm performance of *DroughtTEGO* maize hybrids developed by WEMA Project in low- to mid-altitude maize-growing agroecologies in Kenya and to document the farmers perceptions to the hybrids.

MATERIALS AND METHODS

Germplasm Source

Drought-tolerant maize hybrids developed by the WEMA Project and released for the low- to mid-altitude agroecologies in Kenya were used in this study (Table 1). The hybrids have been bred for drought tolerance (good yield under moderate water stress), with maturity rates between 120 and 145 d and tolerance to northern corn leaf blight, maize streak virus, and gray leaf spot. A total of 58 varieties (39 *DroughtTEGO* hybrids and 19 commercial checks) were grown in 4814 demonstration sites in 17 maize-growing counties in the low- to mid-altitude agroecologies of Kenya (Table 1, Fig. 1).

Site Description, Planting, and Crop Management

Kenya has seven major agroecological zones (AEZs) including Low Tropics (Zone I); Dry Mid-altitudes (Zone II); Dry Transitional (Zone III); Moist Mid-altitudes (Zone IV); Highland Tropical (Zone V); Moist Transitional (Zone VI); and other areas accounting for <5% maize production (Fig. 1). Maize is grown in all the seven agroecological zones, but its production is concentrated in zones IV, V, and VI. The present study focused on the low- to medium-altitude AEZs spread across 17 counties (Fig. 1). The rainfall pattern in the study areas is bi-modal with the first peak in April during the long rainy season (LRS) and November during the short rainy season (SRS) (Fig. 2 and 3).

The hybrids were planted during the LRS (season A) and SRS (season B) of 2015 and 2016 and LRS of 2017. Farmers were randomly selected for inclusion in this study (Fig. 1). The

Table 1. List of *DroughtTEGO* hybrids and commercial check varieties planted per agroecology.

	Agroecology								
Hybrids	Western Kenya		Nyanza	Mt. Kenya		South Rift		Upper eastern	Lower eastern
DroughtTEGO hybrids	WE5120	WE2110	WE1101	WE4140	WE2104	WE4140	WE2101	WE4207	WE5120
	WE5114	WE2109	WE2104	WE5215	WE2101	WE4109	WE1259	WE4117	WE5117
	WE4208	WE2108	WE2106	WE4207	WE1101	WE4108	WE1254	WE4115	WE5114
	WE4207	WE2107	WE2109	WE4141		WE3201	WE1203	WE4109	WE4108
	WE4201	WE2106	WE2110	WE4119		WE3108	WE1101	WE4104	WE3202
	WE4119	WE2104	WE3104	WE4118		WE3106		WE3210	WE3201
	WE4118	WE2101	WE3105	WE4115		WE3105		WE3106	WE3106
	WE4101	WE1259	WE3201	WE4109		WE3104		WE3105	WE3105
	WE3210		WE4109	WE4108		WE3101		WE3104	WE3102
	WE3205		WE4115	WE4101		WE2111		WE3101	WE3101
	WE3201		WE4117	WE3210		WE2110		WE2111	WE2110
	WE3106		WE4140	WE3106		WE2109		WE2110	WE2109
	WE3105		WE4141	WE3104		WE2108		WE2109	WE2106
	WE3104			WE3102		WE2107		WE2108	WE2104
	WE3101			WE2110		WE2106		WE2104	WE2101
	WE2111			WE2108		WE2104		WE1101	WE1101
Check varieties	Check12		Check7	Check7		Check12		Check8	Check6
	Check2		Check6	Heck8		Check1		Check6	Check10
	Check1		Check3	Check6		Check16		Check2	Check11
	Check14		Check18	Check3		Check9		Check13	Check7
	Check4		Check17	Check2				Check9	Check19
	Check5		Check14	Check1				Check15	Heck17
				CHECK9					Check15
				CHECK15					Check15

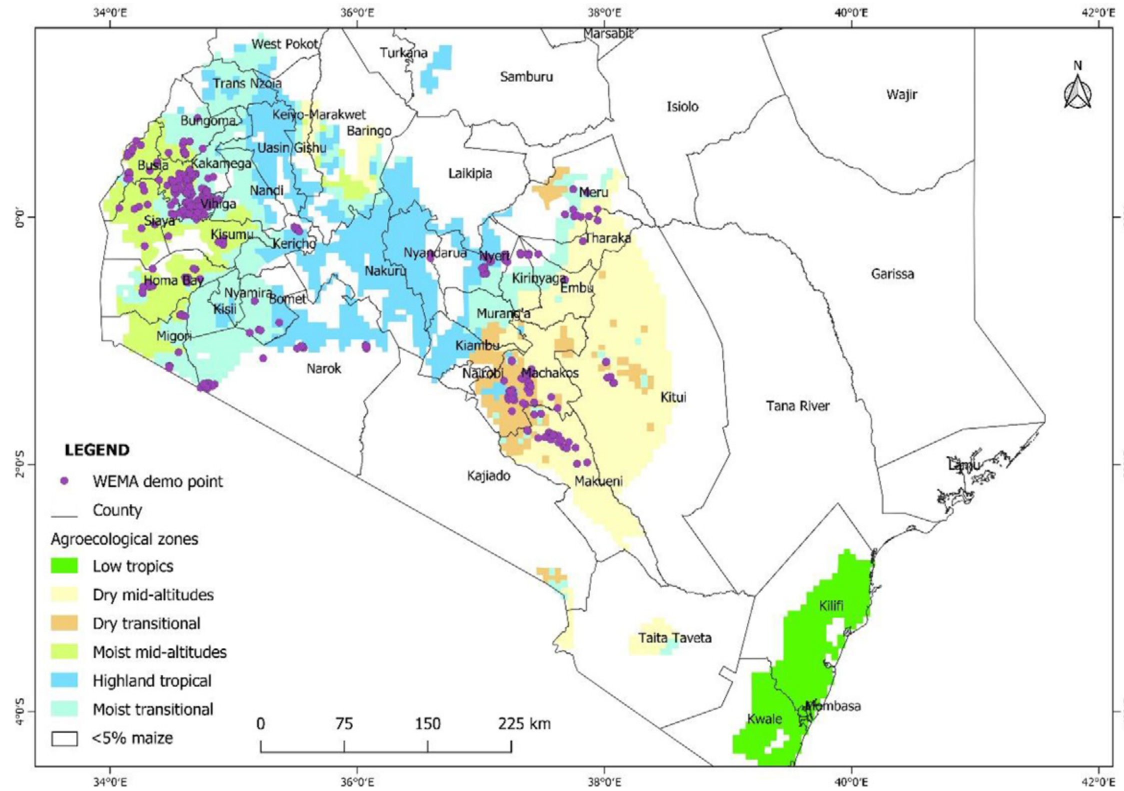

Fig. 1. Site locations of *DroughtTEGO* maize demonstration plots in low- to medium-altitude agroecological zones in 17 counties of Kenya.

DroughtTEGO hybrids and most popular commercial checks were planted in a partially balanced randomized incomplete block design (RCBD). Each hybrid was planted in a 10 by 10 m plot at a spacing of 75 by 25 cm with one plant per hill to give a final population of 53,333 plants ha^{-1}. Each farmer's field was considered as a replication. Analysis of variance was done to test the effects of county, variety, season, and interactions between variety and season on grain yield.

At planting, diammonium phosphate (DAP) fertilizer was applied at rate of 123 kg ha^{-1}; and calcium ammonium nitrate (CAN) was applied at three to five leaf stage at a rate of 123 kg ha^{-1}. Stemborer pests were controlled using an appropriate

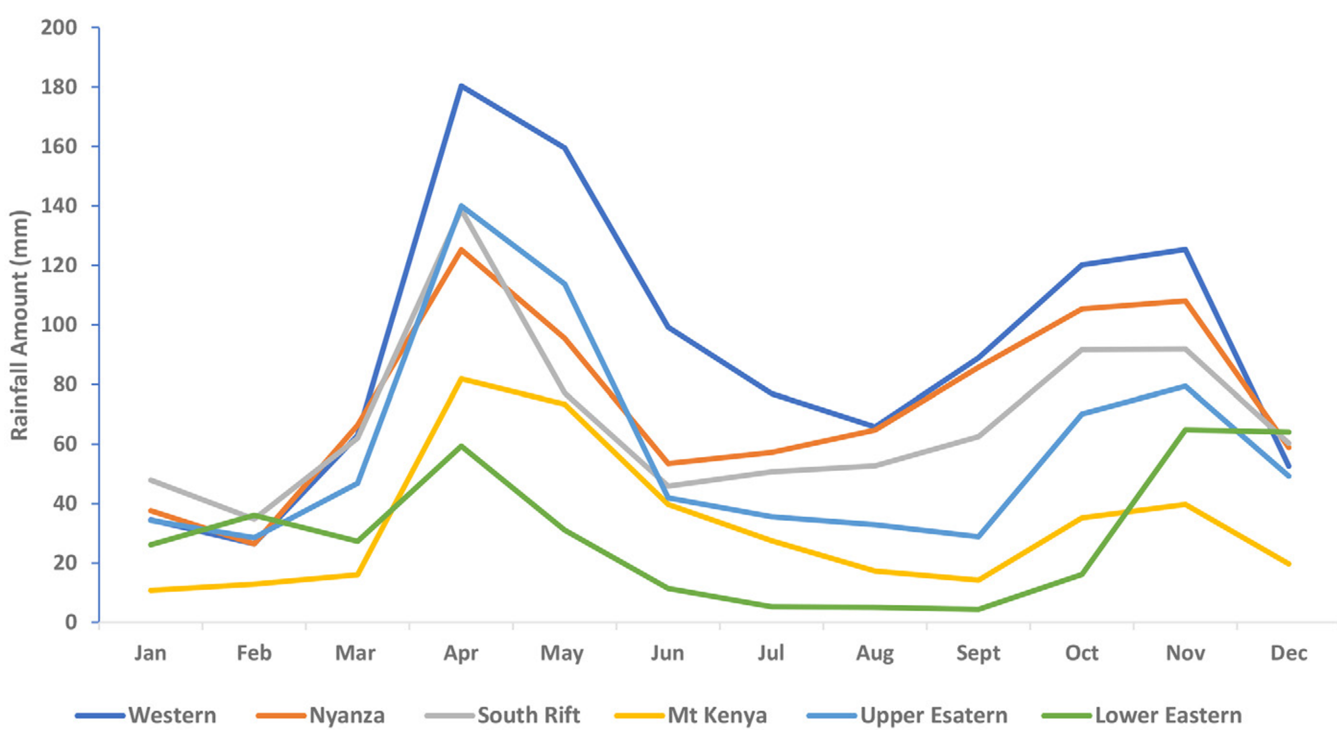

Fig. 2. Average monthly rainfall patterns in low- to medium-altitude agroecologies of Kenya, 2015 to 2017 (Data source: https://www.worldweatheronline.com).

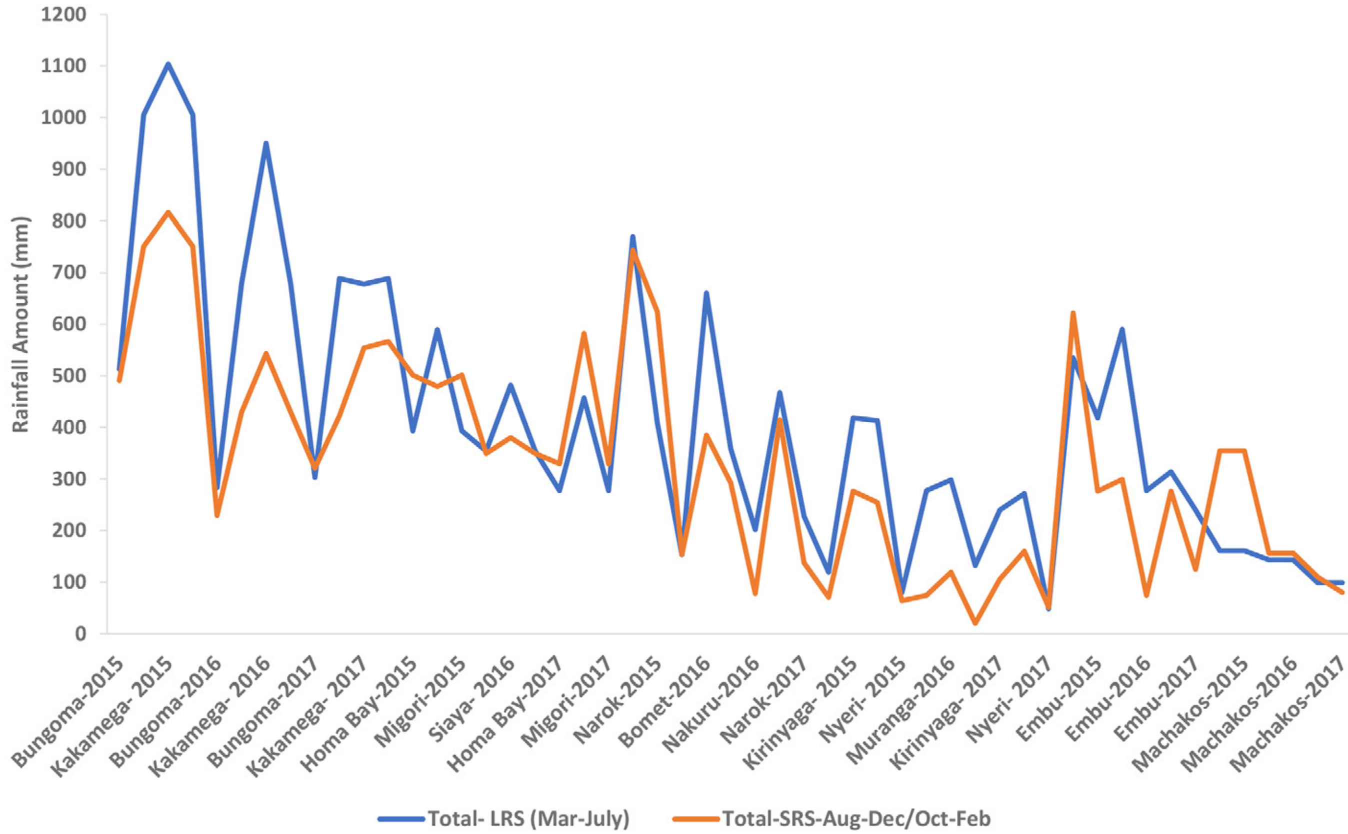

Fig. 3. Total amount of rainfall received in the various low- medium-altitude agroecologies of Kenya during the long and short rains maize growing seasons, 2015 to 2017 (Data source: https://www.worldweatheronline.com).

chemical applied at knee height crop stage. Weeds were controlled by hand weeding throughout the growing season. The demo plots were managed by farmers with the guidance of a research-for-development (R4D) team.

Farmer Variety Evaluation

Farmer field-day workshops were conducted at 246 selected sites; 76 in western Kenya, 57 in Mt. Kenya and upper eastern, 47 in the South Rift, 28 in the lower eastern, and 38 in Nyanza. Farmer groups were invited to view *DroughtTEGO* hybrids and compare them with the performance of the popular commercial varieties. More than 61,000 farmers (57.3% women and 42.7% men) participated in the field day workshops. Five demonstration-host farmers in each agroecology were selected, trained, and determined general disease expression, plant height, root lodging, drought tolerance, maturity period (earliness), stay green character, ease of shelling, shelling percentage, grain type (flint or dent), grain yield, taste– *ugali* (local maize meal), and flour whiteness on a scale of 1 to 5 (where 1 was poor and 5 was best score). Grain type was scored (1–5; 1 being flint and 5 was dent).

At physiological maturity, ears were harvested from each plot. The fresh weight of the harvested ears was recorded. Diseased ears were excluded, and weight of useable ears recorded. Shelling percentage was determined on 12 randomly selected ears. Their fresh weight and grain weight were recorded. The shelling percentage was used to determine grain yield for each plot after correcting for unuseable ears (diseased ears). Grain moisture content was measured from three random grain samples using a DICKEY-john multi-grain moisture tester (Dickey-John Corporation, Auburn, IL). Grain yield was calculated in Mg ha^{-1} using the formulae below (Carangal et al.,1971).

$$\text{Grain yield (Mg ha}^{-1}) = \frac{\text{FEW (kg plot}^{-1}) \times (100 - \text{MC}) \times \text{SP.} \times 10{,}000\ \text{m}^2}{(100 - 13.5) \times \text{Area harvested (plot size)}}$$

where FEW = fresh weight of the ears at harvest; MC = percent moisture content in grains at harvest; SP. = shelling co-efficient; 13.5 = desired moisture content in maize grains at storage and; 10,000 m^2 = 1 ha.

Statistical Analysis

A *t* test was used to compare the *DroughtTEGO* hybrids with the commercial checks varieties for each trait based on an assumption of unequal variances. Combined analysis of variance and means over season/years were computed using GenStat Release 18.2 (PC/Windows 8) for the maize varieties with respect to grain yield. The mean values were compared using least significant difference (LSD) procedure as laid down according to Bliss et al. (1973).

Data collected on grain yield was subjected to statistical analysis using the linear statistical model as described by Fehr (1987):

$$Y_{ijk} = \mu + \beta_j + \lambda_\mathrm{k} + (\mathrm{GE})_\mathrm{ij} + \varepsilon_\mathrm{ijk},$$

where Y_{ijk} = the observation made in the *i*th genotypes on the *j*th replication, in the *k*th season; μ = the overall mean of the character; β_j = the effect of the $\mathrm{j_{th}}$ replication; λ_k = the effect of the *k*th season; $(\mathrm{GE})_{ij}$ = sum of interaction terms of the genotypes and season, and ε_{ijk} = the residual effects.

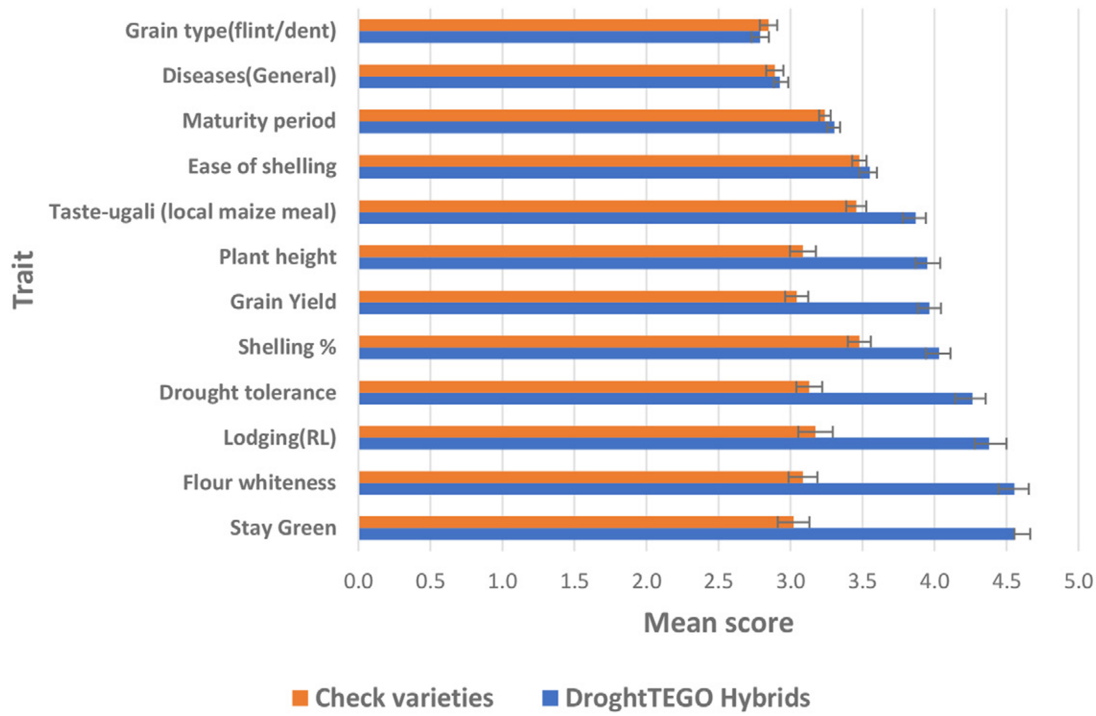

Fig. 4. Farmers' evaluation rating of *DroughtTEGO* vs. commercial check varieties for various traits on a scale of 1 to 5 (1 = poor and 5 = best).

Estimates of heritability and variance components (genotypic and phenotypic components) were calculated from the ANOVA by using the following formula genotypic variance (VG) = (GMS – EMS)/*r*; environmental variance (VE) = EMS; phenotypic variance (VP) = VG + VE; Plot mean basis (h^2BS) = VG /VG + VE; genetic advance (GA) = I × √VP × h^2, where *i* at 20% = 1.40 (Fehr, 1987).

RESULTS AND DISCUSSION

Farmers' Evaluation of *DroughtTEGO* Maize Hybrids

Evaluation of *DroughtTEGO* hybrids against the commercial checks showed that *DroughtTEGO* hybrids rated better on 8 out of the 12 traits scored (Fig. 4, Table 2). The hybrids scored better on stay green character after physiological maturity, flour color (whiteness), root lodging, drought tolerance, shelling percentage, grain yield, plant height, and taste of *ugali* (local maize meal (Fig. 4). However, the *DroughtTEGO* hybrids were similar in rating to commercial checks for general disease reaction in the field, maturity period, ease of shelling, and grain type (flint or dent).

The promotion of *DroughtTEGO* hybrids through on-farm demonstrations and farmer field-day workshops increased awareness of the hybrids to farmers. The reception of farmers and other stakeholders on the suitability of *DroughtTEGO* hybrids for cultivation was very positive. Eagerness to learn more about the hybrids by their willingness to host demonstration plots and participation in field-day workshops by both men and women farmers indicated that these hybrids could increase their farm productivity and livelihoods.

Table 2. Farmers' mean score evaluation rating of *DroughtTEGO* hybrids vs. commercial check varieties for various traits on a scale of 1 to 5 (1 = poor and 5 = best).

Trait	*DroughtTEGO* hybrids	Check varieties	*P*-value
Diseases (general observation)	2.9	2.9	0.457
Plant height	3.9	3.1	0.000***
Root lodge	4.4	3.2	0.002**
Drought tolerance	4.2	3.2	0.002**
Maturity	3.3	3.2	0.460
Stay green	4.6	3.0	0.000***
Ease of shelling	3.5	3.5	0.260
Shelling %	4.1	3.5	0.000***
Grain type	2.8	2.9	0.330
Grain yield	4.0	3.1	0.000***
Taste of ugali (local maize meal)	3.8	3.5	0.013**
Flour whiteness	4.5	3.1	0.000***

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

Table 3. Analysis of variance for yield (Mg ha^{-1}).

Variable	df	Sum of squares	Mean squares	*F* value	Probability of *F*
County	17	730.6981	42.9822	54.7	<0.001
Variety	59	1091.205	18.495	23.54	<0.001
Season	4	52.6428	13.1607	16.75	<0.001
Variety × Season	89	167.0675	1.8772	2.39	<0.001
Residual	2470	1940.854	0.7858		
Total	2639	3982.468	1.5091		

In this study, it was observed that more women (57%), than male farmers participated in farming activities including hosting the demonstration plots and participation in the field days for exchange of knowledge. It was noted that women were more engaged in farming activities than men because of their desire to ensure food security for their families. They were also easier to mobilize to form farmer groups. An interview with Doris Anjawa, Field Coordinator at the Rural Outreach Program-Africa in western Kenya, during the field day workshops reported that low involvements of male farmers were attributed to many men's belief that farming is women's work. Men were most interested in grain marketing and sharing the income.

The farmers were more interested in stay-green, white flour (milling quality), root lodging resistance, drought tolerance, and shelling percentage (Fig. 4). Stay-green character after physiological maturity of the *DroughtTEGO* hybrids, associated with drought tolerance, is important for farmers who keep livestock because after harvest, the green stalks serve as animal feed. Similar observation was reported for the wide adoption in the West African savanna of open-pollinated, TZB-SR variety with flinty grains that were suitable for storage and possess high milling quality preferred by farmers (Oikeh et al., 1998). Shelling percentage was appreciated by most farmers, one of whom (the late Omari Majoni in Mumias, personal communication, 2015) reported up to 2.5 tea cups of grain from one ear of WE1101 *DroughtTEGO* hybrid, compared with 1.5 from the previous hybrid he was planting. Plant height, grain yield, and taste of maize meal were also rated better for *DroughtTEGO* hybrids (Table 2). Other studies have reported that farmers rated high grain yield, disease resistances, good grain milling quality, and drought tolerance to be the most important traits in adoption of new maize hybrids (Wang et al., 2017; Nyaligwa et al., 2016; Afriyie-Debrah et al., 2018).

Increased awareness of the benefits of new seed varieties are critical for increasing farm productivity in eastern and southern Africa (Langyintuo et al., 2008). This has been a slow process; however adoption barriers are being overcome by conducting on-farm demonstration studies and linking farmers to seed companies through field days (Langyintuo et al., 2008). Farmers' perceptions about a new variety plays a vital role in the adoption process (Witcombe et al., 2003; vom Brocke et al., 2010; Trouche et al., 2012). However, it is important to note that although most farmers obtain information on improved maize hybrids, only a few adopt these new technologies (Wambugu et al., 2012).

One hybrid WE1101 showed consistently high yields that generally ranged from 5 to 6 Mg ha^{-1} since its release in 2013. This hybrid has a medium maturity period (120 d) in most of the agroecologies across Kenya. Muinga et al. (2019) reported

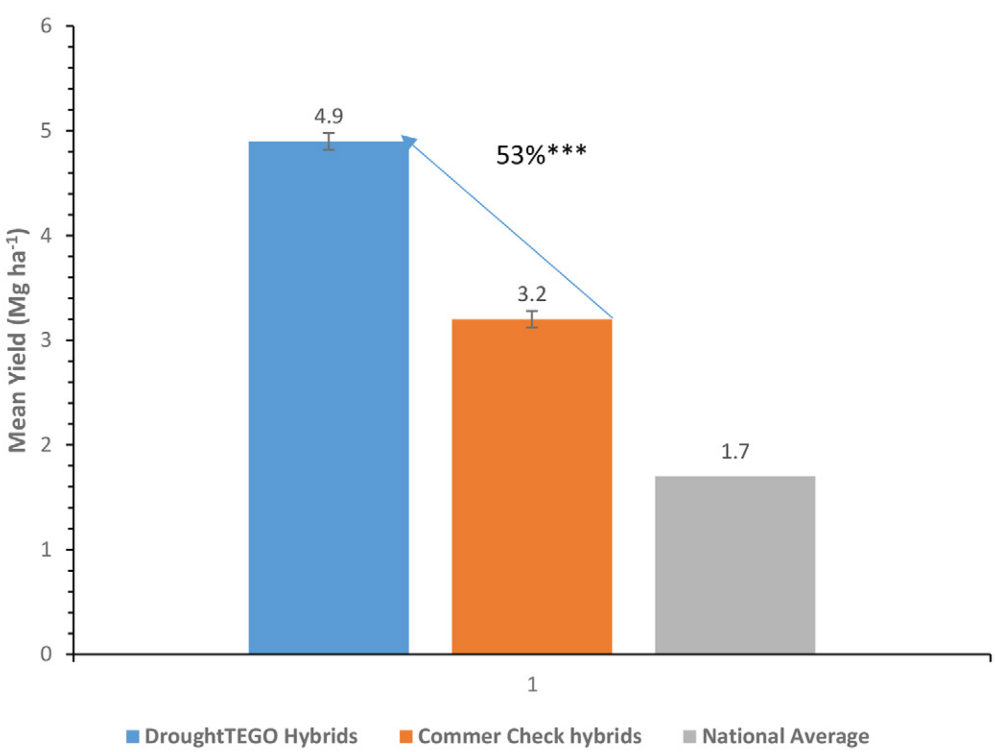

Fig. 5. Mean yield for 39 *DroughtTEGO* hybrids compared with popular commercial checks and the national maize yield average over five growing seasons (2015LR, 2015SR, 2016LR, 2016SR, and 2017LR) (Source: National average: FAOSTAT, 2018).

that the adoption rate of *DroughtTEGO* hybrids was 26%, after only 3 yr of introduction to smallholder farmers in Kenya. In addition, the study showed that 62% of the farmers interviewed were aware of at least one *DroughtTEGO* hybrid and that 42% of them were considering purchasing WE1101 *DroughtTEGO* hybrid seed for planting. Farmers in some parts of western Kenya were attracted to *DroughtTEGO* hybrids because of drought tolerance, earliness, and high yields when compared to late-maturing hybrids like H614 and H6213 grown in the region. They could also plant two-season crops of *DroughtTEGO* hybrids in a year, for food security and income from surplus grain.

Grain Yield Performance of *DroughtTEGO* Maize Hybrids

Analysis of variance for the on-farm data showed significant interaction between variety and season as well ($P \leq 0.001$) and yield differences among counties, varieties, and seasons ($P < 0.001$). Table 3 shows that the varieties perform significantly different in different counties and seasons.

Combined analysis across the agroecologies over the five seasons showed that *DroughtTEGO* hybrids had higher productivity compared with commercial checks in Kenya (Fig. 5). The *DroughtTEGO* hybrids had mean yield of 4.9 Mg ha^{-1} compared with 3.2 Mg ha^{-1} for commercial checks over the five seasons. This is a 53% yield advantage over commercial checks and 188% yield advantage over the Kenya national average maize yield during the evaluation period, 2015 to 2017.

The best 10 *DroughtTEGO* hybrids had mean yields of 5.3 to 6.3 Mg ha^{-1} compared with 4.1 Mg ha^{-1} for the best commercial check hybrid across all locations and years (Table 4). This represents a yield advantage of 29 to 54% (Table 4). Out of the 39 *DroughtTEGO* hybrids planted, 20 hybrids had a greater than 20% yield advantage over the best commercial check hybrid, and a greater than 50% yield advantage over mean of checks. *DroughtTEGO* hybrids have potential yield of 4.2 Mg ha^{-1} under managed drought and up to 9.1 Mg ha^{-1} under optimum-moisture (well-watered) conditions (https://www.kephis.org/images/Uploads/UPNVLIST.pdf), compared to 4.3 to 7.8 Mg/ha^{-1} (https://www.infonet-biovision.org/PlantHealth/Crops/Maize).

Table 4. Mean yield of top 10 *DroughtTEGO* hybrids and popular commercial checks over five seasons (2015A–2017A) on 753 demonstration farms in Kenya.

Hybrids	Grain yield	SE	Percent above best check	Percent above mean check
	Mg ha^{-1}		%	
WE5213	6.3	0.4	53.7	96.9
WE4207	5.8	0.2	42.0	81.9
WE5205	5.7	0.4	39.7	79.0
WE4208	5.5	0.2	34.3	72.1
WE2108	5.5	0.1	33.0	70.4
WE3104	5.4	0.2	32.3	69.5
WE1259	5.4	0.2	31.6	68.6
WE2107	5.4	0.2	31.4	68.3
WE5215	5.3	0.2	30.4	67.0
WE3105	5.3	0.1	29.4	65.8
check8	4.1	0.2		
check5	4.0	0.1		
check4	3.9	0.1		
check13	3.8	0.4		
check9	3.8	0.1		
check1	3.7	0.1		
check2	3.7	0.1		
check12	3.5	0.2		
check6	3.3	0.1		
check7	3.2	0.1		
Heritability	0.91			
Grand mean	4.5			
Check mean	3.2			
LSD (0.05)	0.6			
CV, %	21.1			
Genotype significance	0.000			

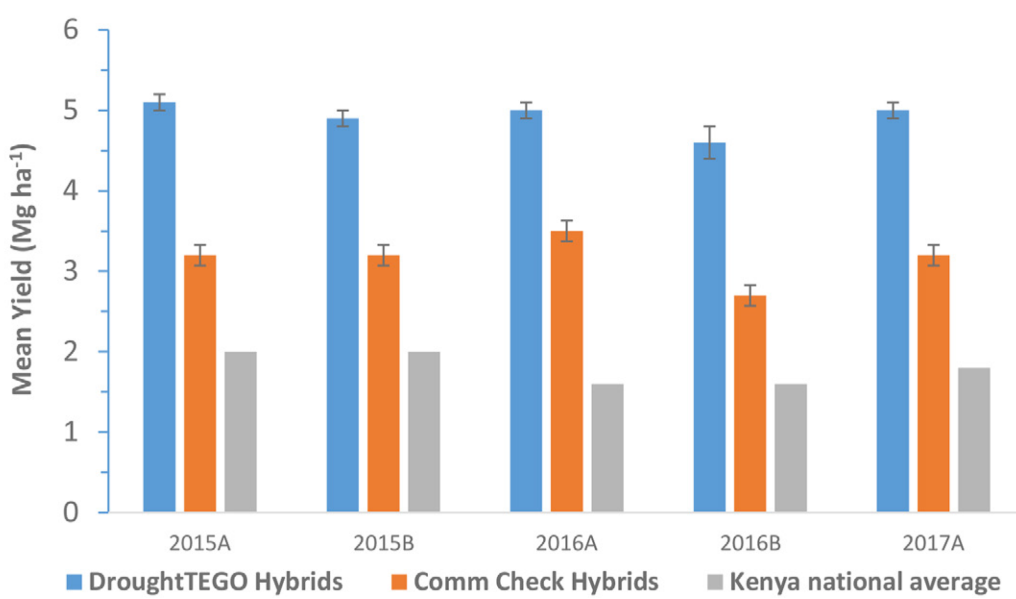

Fig. 6. Mean yield of *DroughtTEGO* hybrids and popular commercial check varieties over five seasons (2015A–2017A). (Source: Kenya national average: FAOSTAT, 2018)

Table 5. *DroughtTEGO* hybrids mean yield (Mg ha^{-1}) across 17 counties over five seasons (2015A–2017A).

County	Agroecology	*DroughtTEGO* mean yield	Check mean yield	SE	SD	Percent above check mean	LSD (0.05)	CV
		—— Mg ha^{-1} ——						%
Kakamega	Western Kenya	4.9	3.6	0.1	0.5	36.1	0.8	20.1
Vihiga	Western Kenya	4.2	3.3	0.1	0.6	27.3	1.0	22.1
Busia	Western Kenya	4.5	3.2	0.2	0.8	40.6	14	22.4
Bungoma	Western Kenya	4.7	3.6	0.1	0.7	30.6	1.0	14.7
Meru	Upper eastern	5.3	4.0	0.2	0.9	32.5	1.7	22.8
Embu	Upper eastern	5.1	3.9	0.2	0.8	30.8	1.5	19.5
Narok	South Rift	3.7	3.3	0.1	0.4	12.1	0.9	19.6
Nakuru	South Rift	5.3	3.8	0.3	1.0	39.5	1.5	20.7
Bomet	South Rift	4.4	3.8	0.2	0.5	15.8	1.0	18.0
Nyeri	Mt. Kenya	4.4	2.9	0.2	0.8	51.7	1.1	17.9
Muranga	Mt. Kenya	5.0	3.0	0.3	1.2	66.7	1.7	22.9
Kirinyaga	Mt. Kenya	4.9	3.3	0.1	0.8	48.5	1.2	19.5
Makueni	Lower eastern	4.1	2.6	0.2	0.8	57.7	1.0	20.3
Machakos	Lower eastern	4.3	2.8	0.2	0.8	53.6	0.7	15.5
Siaya	Nyanza	4.4	3.0	0.3	1.0	46.7	1.0	18.4
Migori	Nyanza	4.7	3.0	0.2	1.0	56.7	1.1	18.4
Homa Bay	Nyanza	4.5	2.5	0.2	0.9	80.0	1.5	25.1

Hybrids Performance Per Growing Season

Table 3 shows that the varieties performed significantly different in different counties and seasons. The 2015 LRS had the highest yield, while 2016 SRS showed the least (Fig. 6). These differences may be attributed to differences in rainfall amount and duration (Fig. 2 and 3). During the LRSs (2015A, 2016A, 2017A) the *DroughtTEGO* hybrids had 43 to 59% mean yield advantage over the commercial checks, while in the SRSs (2015B and 2016B), *DroughtTEGO* hybrids had 53 to 73% yield advantage over the commercial checks . These findings suggest that the *DroughtTEGO* hybrids were superior in LRS and SRSs. Climate data showed that the highest rainfall totals were observed in April to May and October to November (Fig. 1). However, Mt. Kenya and lower eastern regions had significantly lower rainfall totals when compared to the other agroecologies. In these regions, *DroughtTEGO* hybrids provided higher and more stable yields when compared with the commercial checks. Rainfall data (Fig. 2) indicated that 2016 received less rainfall both in LRS and SRSs when compared to 2015 and 2017. In 2016 SRS, prolonged drought was experienced in Kenya leading to high moisture stress but *DroughtTEGO* hybrids showed the highest (70%) yield advantage over commercial checks.

Yield Performance in the Agroecologies

There was a significant yield difference between *DroughtTEGO* and commercial checks; and the varieties performed significantly different in the different counties and seasons (Tables 5 and 6). The highest hybrid yields were observed in Kakamega, Nakuru, Meru, Embu, and Muranga, and the lowest yields were observed in the lower eastern counties of Machakos and Makueni. It was also observed that different hybrids performed better in some counties than others; while some hybrids were among the best hybrids across the counties.

Yield Performance in Western Kenya

Western Kenya falls within the moist mid-altitude agroecological zone (Fig. 1). In the four counties of Kakamega, Vihiga, Busia, and Bungoma in western Kenya, *DroughtTEGO* hybrids yields ranged from 4.2 to 4.9 Mg ha^{-1} (Table 5). These yields were 27 to 36% higher than that of commercial check hybrids. The individual mean yield of best 10 *DroughtTEGO* hybrids ranged from 4.4 to 6.7 Mg ha^{-1} across the counties, which were higher than that of commercial checks, that ranged from 2.9 to 4.0 Mg ha^{-1} (Table 7). There were 10 *DroughtTEGO* hybrids (WE4207, WE4208, WE1101, WE2107, WE2108, WE3104, WE3105, WE3106, WE3210, and WE1254) that were among the top 10 hybrids in more than one county (Table 7). Most of the *DroughtTEGO* hybrids performed very well in western Kenya that had high and well distributed rainfall when compared to other agroecologies (Fig. 2 and 3).

Performance in Nyanza (Lake Victoria) Region

Nyanza region falls within the moist mid-altitude AEZ (Fig. 1). *DroughtTEGO* hybrids yields ranged from 4.4 to 4.7 Mg ha^{-1} while commercial checks yields ranged from 2.5 to 3.0 Mg ha^{-1} in Siaya, Homa Bay, and Migori Counties

Table 6. *t*-test analysis (two-sample assuming equal variances) of yield data for *DroughtTEGO* and commercial checks†.

Group	Observations	Mean	SE	SD	95% Confidence interval, lower limit	95% Confidence interval, upper limit
DroughtTEGO hybrids	17	4.61	0.11	0.44	4.39	4.84
Commercial checks	17	3.27	0.11	0.46	3.04	3.51
Combined	34	3.94	0.14	0.81	3.66	4.22
Difference		–1.34	0.15		–1.65	–1.03

† Diff = mean(checks) - mean(*DroughtTEGO*); $t = –8.7619$; Ho: diff = 0 degrees of freedom = 32; Ha: diff < 0; Ha: diff! = 0; Ha: diff > 0 $P (T < t) = 0.0000$; $P (|T| > |t|) = 0.0000$; $P (T > t) = 1.0000$.

Table 7. On-farm mean grain yield of *DroughtTEGO* hybrids and popular commercial check varieties in western Kenya (2015–2017).

	County																
	Kakamega		Vihiga		Busia		Bungoma			Kakamega		Vihiga		Busia		Bungoma	
Hybrid	GY†	Rank	GY†	Rank	GY†	Rank	GY†	Rank	Hybrid	GY†	Rank	GY†	Rank	GY†	Rank	GY†	Rank
	Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}			Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}	
WE1101	5.3	2	5.0	2	4.5	8	4.4	16	WE3106	4.9	11	4.1	18	5.1	2	5.2	4
WE1203	5.3	2	4.5	7	3.8	18	–	–	WE3201	5.1	9	–	–	–	–	–	–
WE1254	5.0	10	4.4	10	–	–	4.7	8	WE3205	4.8	12	4.3	14	4.4	11	3.8	23
WE1259	4.8	12	5.0	3	–	–	–	–	WE3210	5.1	8	4.4	10	–	–	4.8	7
WE2101	4.7	18	3.9	24	–	–	4.2	21	WE4101	4.7	18	3.9	23	–	–	4.6	10
WE2104	4.8	12	4.4	10	4.4	11	4.3	19	WE4104	4.3	27	–	–	5.1	2	–	–
WE2106	4.8	12	4.3	14	–	–	4.6	10	WE4108	–	–	–	–	5.6	1	–	–
WE2107	4.7	18	4.7	5	–	–	4.9	6	WE4115	4.6	23	3.2	26	4.4	11	–	–
WE2108	5.2	5	4.4	10	4.3	15	6.7	1	WE4118	4.1	28	4.0	19	4.5	8	4.4	16
WE2109	4.8	12	4.3	14	4.6	5	4.5	14	WE4119	5.2	6	4.2	17	–	–	4.7	8
WE2110	4.5	25	4.5	7	4.4	11	4.5	14	WE4140	–	–	–	–	4.6	5	–	–
WE2111	4.8	12	4.0	20	4.6	5	4.6	13	WE4207	5.7	1	4.5	7	–	–	5.8	2
WE3101	4.7	18	4.0	21	–	–	4.6	10	WE4208	5.3	2	4.9	4	4.5	8	4.3	19
WE3104	4.7	18	5.1	1	–	–	5.0	5	WE5205	4.5	25	2.5	29	–	–	–	–
WE3105	4.6	23	4.7	5	4.9	4	5.5	3	WE5215	5.1	7	–	–	–	–	4.4	16
Check1	3.8	29	3.9	22	4.3	15	3.4	26	Check7	–	–	–	–	3.1	20	–	–
Check2	3.7	30	2.9	28	–	–	4.0	22	Check12	–	–	–	–	3.0	21	–	–
Check3	–	–	–	–	2.8	22	–	–	Check14	–	–	–	–	3.6	19	–	–
Check4	3.5	31	2.9	27	–	–	3.6	24	Check17	–	–	–	–	2.6	23	–	–
Check5	3.5	32	3.5	25	3.9	17	3.5	25	Check18	–	–	–	–	2.3	24	–	–
Mean	4.7	na‡	4.2	na	4.1	na	4.6	na									
LSD (0.05)	0.8	na	1.0	na	1.4	na	1.0	na									
CV,%	20.1	na	22.1	na	22.4	na	14.6	na									
No. of location	176	na	124	na	24	na	32	na									
Genotype signifiance	0.00	na	0.00	na	0.00	na	0.00	na									

† Mean grain yield.

‡ na, Not applicable.

Table 8. On-farm mean grain yield for *DroughtTEGO* hybrids and popular commercial check varieties in Nyanza region in Kenya (2015–2017).

	County												
	Migori		Siaya		Homa-Bay			Migori		Siaya		Homa-Bay	
Hybrid	GY†	Rank	GY†	Rank	GY†	Rank	Hybrid	GY†	Rank	GY†	Rank	GY†	Rank
	Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}			Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}	
WE1101	4.3	7	4.6	4	4.8	3	WE3201	6.0	1	–	–	4.4	5
WE1203	–	–	4.4	5	–	–	WE4109	–	–	–	–	4.0	11
WE2106	4.9	3	–	–	4.7	4	WE4108	–	–	–	–	4.2	10
WE2110	4.4	4	–	–	4.3	7	WE4115	4.7	4	–	–	4.4	5
WE2111	–	–	4.9	2	–	–	WE4117	4.7	4	–	–	4.3	7
WE3101	–	–	3.8	7	–	–	WE4140	4.3	7	–	–	3.9	13
WE3102	–	–	–	–	4.3	7	WE4141	3.8	10	–	–	–	–
WE3104	–	–	4.8	3	5.8	1	WE5205	4.2	9	3.6	8	4.0	11
WE3105	5.6	2	5.1	1	5.1	2							
Check3	–	–	3.5	9	–	–							
Check6	3.3	12	–	–	–	–							
Check7	3.1	13	3.9	6	2.4	16							
Check12	3.6	11	2.2	12	–	–							
Check17	2.8	14	2.6	10	2.5	15							
Check18	2.4	15	2.6	10	2.7	14							
Mean	4.1	na‡	3.8	na	4.0	na							
LSD (0.05)	1.1	na	1.0	na	1.5	na							
CV, %	18.4	na	18.4	na	25.1	na							
No. of location	9	na	15	na	13	na							
Genotype signifiance	0.00	na	0.00	na	0.00	na							

† Mean grain yield.
‡ na, Not applicable.

(Table 5). The individual mean yield of the best 10 hybrids ranged from 3.8 to 6.0 Mg ha^{-1}; higher than that of commercial checks that ranged from 2.2 to 4.0 Mg ha^{-1}(Table 8). There were 11 *DroughtTEGO* hybrids (WE3201, WE3105, WE2106, WE4115, WE4117, WE2110, WE1101, WE5120, WE3104, and WE3101) that were among the top performing hybrids across three counties.

DroughtTEGO hybrids yields were slightly lower in the Nyanza region compared to the neighboring western Kenya agroecology. This may be attributed to frequent drought events in the region especially during tasseling and silking growth stages between May and June (Fig. 2 and 3). Second, Nyanza region is characterized by low soil fertility and incidences of *Striga* weed which limit hybrid yield potential (Ndwiga et al., 2013). Most of the demonstration trials in the area were discontinued because of *Striga* weed infestation.

Performance in Upper and Lower Eastern Kenya

Upper and lower eastern agroecologies fall within the dry mid-altitudes and the dry-transitional AEZs (Fig. 1). In upper eastern, *DroughtTEGO* hybrids yields ranged from 5.1 to 5.3 Mg ha^{-1} in Meru and Embu. These yields were higher than that of commercial checks that ranged from 3.9 to 4.0 Mg ha^{-1} in the two counties (Table 5). The individual yield of the best 10 hybrids ranged from 4.9 to 6.5 Mg ha^{-1}, which were higher than that of commercial checks at 3.5 to 4.8 Mg ha^{-1}(Table 9). Four *DroughtTEGO* hybrids (WE1101, WE2106, WE3105, and WE3106) were among the top 10 hybrids in both counties.

In the lower eastern, *DroughtTEGO* hybrids yields ranged from 4.1 to 4.3 Mg ha^{-1} in Machakos and Makueni. These yields were higher than that of commercial check hybrids that ranged from 2.6 to 2.8 Mg ha^{-1}. (Table 6). The yields of the best 10 hybrids ranged from 3.6 to 4.9 Mg ha^{-1}, higher than that of commercial checks yields that ranged from 1.9 to 3.0 Mg ha^{-1} (Table 9).). Three D*roughtTEGO* hybrids (WE1101, WE2106, and WE3101) were among the top 10 hybrids common in the two counties.

Maize farmers in Upper and lower eastern agroecologies are mostly in marginal areas that receive less rainfall, which is also not evenly distributed during the maize-growing season. Most of the rainfall is received at planting and early seedling stages (April–May and October–December) of maize crops (Fig. 2 and 3) with often drought stress at flowering and grain-filling stages. Most hybrids, including the early varieties yield less when they survive drought, especially in Machakos and Makueni Counties that received the least rainfall (Fig. 2 and 3). The yields reported for *DroughtTEGO* hybrids showed that adoption of drought-tolerant hybrids is important to protect maize yields in this agroecology.

Performance in the Mt. Kenya Region

Mt. Kenya Regions lies in the moist transitional maize-growing AEZ of Kenya (Fig. 1). *DroughtTEGO* hybrids yields ranged from 4.4 to 5.0 Mg ha^{-1}, which were higher than that of commercial checks hybrids that ranged from 2.9 to 3.3 Mg ha^{-1} in Nyeri, Muranga, and Kirinyaga Counties (Table 5). The individual mean yield of the best 10 hybrids ranged from 4.3 to 6.6 Mg ha^{-1}; higher than commercial checks whose yields ranged from 1.7 to 3.6 Mg ha^{-1} (Table 10). Five *DroughtTEGO* hybrids (WE4207, WE3105, WE3106, WE2108, and WE3104) were among the top 10 common hybrids across the three counties.

The rainfall patterns showed that less rains were received in Mt. Kenya in 2015 to 2017, apart from lower eastern, compared with the other agroecologies in Kenya (Fig. 2 and 3). In spite of

Table 9. On-farm mean grain yield for *DroughtTEGO* hybrids and popular commercial check varieties in Upper (Meru and Embu) and Lower (Makueni and Machakos) eastern counties in Kenya (2015–2017).

Hybrid	Meru GY†	Meru Rank	Embu GY†	Embu Rank	Makueni GY†	Makueni Rank	Machakos GY†	Machakos Rank
	Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}	
WE1101	5.6	4	5.0	9	3.7	6	4.4	3
WE1203	4.7	12	–	–	–	–	–	–
WE1259	6.5	1	–	–	–	–	–	–
WE2101	–	–	5.4	6	4.6	1	–	–
WE2104	–	–	5.7	5	4.2	4	–	–
WE2106	4.9	9	6.0	2	4.1	5	4.5	2
WE2109	5.4	5	–	–	–	–	–	–
WE2110	–	–	–	–	4.5	2	–	–
WE2111	5.4	6	4.6	12	–	–	–	–
WE3101	5.2	7	–	–	4.3	3	4.1	5
WE3104	–	–	4.8	11	–	–	–	–
WE3105	5.8	2	5.1	7	–	–	–	–
Check6	3.5	15	3.6	18	2.6	11	2.7	9
Check7	–	–	–	–	2.9	7	2.6	12
Check8	4.8	11	3.9	17	–	–	–	–
Check9	–	–	4.0	16	–	–	–	–
Check10	–	–	–	–	–	–	3.0	7
Mean	5.0	na‡	4.9	na	3.5	na	3.6	na
LSD (0.05)	1.7	na	1.5	na	1.0	na	0.7	na
CV, %	22.8	na	19.5	na	20.3	na	15.5	na
No. of location	11	na	10	na	7	na	17	na
Genotype signifiance	0.00	na	0.00	na	0.00	na	0.00	na

Hybrid	Meru GY†	Meru Rank	Embu GY†	Embu Rank	Makueni GY†	Makueni Rank	Machakos GY†	Machakos Rank
	Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}	
WE3106	5.7	3	5.8	4	–	–	4.4	3
WE3201	3.7	13	–	–	–	–	–	–
WE4104	4.9	9	4.6	12	–	–	–	–
WE4109	–	–	5.1	7	–	–	–	–
WE4108	–	–	4.9	10	3.7	6	–	–
WE4115	–	–	4.2	13	–	–	–	–
WE4117	5.2	7	4.2	13	–	–	–	–
WE4140	–	–	–	–	–	–	3.8	6
WE4141	–	–	–	–	–	–	4.9	1
WE4207	–	–	6.0	2	–	–	–	–
WE5230	–	–	4.1	15	–	–	–	–
WE5215	–	–	6.2	1	–	–	–	–
Check11	–	–	–	–	1.9	11	2.7	9
Check13	3.6	14	–	–	–	–	–	–
Check15	–	–	–	–	2.8	9	2.8	8
Check19	–	–	–	–	2.9	8	2.7	9

† Mean grain yield.

‡ na, Not applicable.

Table 10. On-farm mean grain yield for *DroughtTEGO* hybrids and popular commercial check varieties in Mt. Kenya Region (2015–2017).

	County												
	Kirinyaga		Nyeri		Muranga			Kirinyaga		Nyeri		Muranga	
Hybrid	GY†	Rank	GY†	Rank	GY†	Rank	Hybrid	GY†	Rank	GY†	Rank	GY†	Rank
	Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}			Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}	
WE1101	5.0	10	5.0	3	4.9	4	WE4101	4.2	20	–	–	–	–
WE1203	–	–	3.6	15	–	–	WE4104	4.9	11	–	–	–	–
WE1259	–	–	4.5	5	–	–	WE4109	4.2	20	–	–	–	–
WE2101	4.6	16	–	–	–	–	WE4108	4.5	19	–	–	5.7	2
WE2104	5.1	8	–	–	–	–	WE4115	4.9	11	–	–	–	–
WE2106	4.6	16	4.3	9	4.6	6	WE4117	4	25	–	–	–	–
WE2107	–	–	5.0	3	–	–	WE4119	4.8	15	3.9	12		
WE2108	5.2	6	5.3	2	–	–	WE4140	4.5	19	–	–	–	–
WE2109	5.2	7	4.5	5	–	–	WE4207	6.6	1	–	–	–	–
WE2110	4.9	11	4.5	5	–	–	WE4208	–	–	–	–	5.4	3
WE2111	4.6	16	4.3	9	4.5	7	WE5107	3.9	27	3.4	16	–	–
WE3101	–	–	3.8	13	–	–	WE5120	5.8	3	–	–	–	–
WE3102	4.1	22	3.6	15	–	–	WE5205	6.3	2	–	–	4.7	5
WE3104	5.1	8	4.3	9	–	–	WE5210	5.1	8	3.4	18	–	–
WE3105	5.8	3	4.5	5	6.1	1	WE5213	–	–	5.8	1	–	–
WE3106	5.4	5	–	–	4.2	8	WE5230	4.0	23	–	–	–	–
WE3210	–	–	3.7	14	–	–	WE5215	4.9	11	–	–	–	–
Check1	–	–	–	–	3.3	11	Check6	2.9	27	–	–	3.4	10
Check2	3.5	25	–	–	3.1	12	Check8	3.8	24	2.4	20	3.6	9
Check3	–	–	3.4	16	–	–	Check9	3.0	26	2.9	19	1.7	13
Mean	4.7	na‡	4.1	na	4.3	na							
LSD (0.05)	1.2	na	1.0	na	1.7	na							
CV, %	19.5	na	17.9	na	22.9	na							
No. of location	22	na	27	na	13	na							
Genotype signifiance	0.00	na	0.00	na	0.00	na							

† Mean grain yield.

‡ na, Not applicable.

the less amount of rainfall received, *DroughtTEGO* hybrids had some of the highest yields in this agroecology; with yield advantage of 83 to 153% over commercial checks. Most of the commercial checks were severely impacted by drought stress, while *DroughtTEGO* hybrids were resilient to the stress.

Performance in South Rift Valley

South Rift agroecology falls within the moist-transitional and highland tropical agroecologies in Kenya (Fig. 1). This study focused on the moist-transitional part of the counties, excluding the highlands. In this agroecology, *DroughtTEGO* hybrids yields ranged from 3.7 to 5.3 Mg ha^{-1}; higher than that of commercial checks that ranged from 3.3 to 3.8 Mg ha^{-1} in Narok, Bomet, and Nakuru Counties in South Rift Valley (Table 5). The individual mean yield of the best 10 hybrids ranged from 3.7 to 6.1 Mg ha^{-1}. These yields were higher than that of commercial checks that ranged from 3.1 to 5.2 Mg ha^{-1} (Table 11). Six *DroughtTEGO* hybrids (WE1101, WE2101, WE2104, WE2106, WE2108, and WE2110) were ranked among the top 10 common hybrids across the three counties.

The low yield advantage (17–19%) of *DroughtTEGO* hybrids compared with the potential of these hybrids, could be attributed to the incidence of maize lethal necrosis (MLN) disease that is prevalent in this agroecology. The *DroughtTEGO* hybrids used in this study are susceptible to MLN disease. However, from the yields reported, *DroughtTEGO* hybrids out-performed the commercial checks and were well adapted to this agroecology.

The drought-tolerant hybrids were developed for high and stable yield under water stressed environments to help farmers mitigate drought stress in maize farming (Beyene et al., 2016; 2017). The variable responses of the hybrids in different agroecologies and counties across seasons showed that different hybrids are better suited for different agroecologies and that rainfall patterns affected hybrid performance. The interaction between the different genotypes and environment (either dry or moist) was key yield determinant for the hybrids. The top 10 *DroughtTEGO* hybrids produced the highest grain yields that ranged from 4.4 to 6.7 Mg ha^{-1} in the counties of Kakamega, Meru, Embu, Murang'a and Kirinyaga, while lower yields that ranged from 3.6 to 4.9 Mg ha^{-1} (top 10 hybrids) were obtained in Makueni and Machakos counties. However, the magnitude of the impact of *DroughtTEGO* hybrids were greater in the low potential areas (63–89%) than in the high potential areas (35–68%) when compared with commercial hybrids. This is because the *DroughtTEGO* hybrids were developed for agroecologies that generally have limited amounts of rainfall (Fig. 2 and 3).

Intermittent drought spells were experienced during active growth period of the hybrids in the five seasons (Fig. 3). The longest drought spell was in 2016 SRS when the yields for both sets of *DroughtTEGO* hybrids and commercial hybrids were significantly lower when compared with the other seasons. According to Uhe et al. (2017), there was severe drought in most parts of Kenya during October to December 2016 into early 2017. During the period, most farmers lost their maize

Table 11. On-farm mean grain yield for *DroughtTEGO* hybrids and popular commercial check varieties in South Rift (2015–2017).

	County												
	Bomet		Narok		Nakuru			Bomet		Narok		Nakuru	
Hybrid	GY†	Rank	GY†	Rank	GY†	Rank	Hybrid	GY†	Rank	GY†	Rank	GY†	Rank
	Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}			Mg ha^{-1}		Mg ha^{-1}		Mg ha^{-1}	
WE1101	4.9	2	4.3	2	5.4	4	WE3104	–	–	–	–	5.2	5
WE1254	–	–	3.7	10	–	–	WE3106	–	–	3.8	6	–	–
WE2101	4.0	5	3.4	14	4.7	7	WE3201	–	–	3.2	16	–	–
WE2104	4.1	4	3.9	5	–	–	WE4109	–	–	–	–	6.1	1
WE2106	4.3	3	3.8	6	–	–	WE4108	–	–	–	–	6.0	2
WE2108	5.1	1	4.1	3	–	–	WE4115	–	–	3.8	6	–	–
WE2109	–	–	3.8	6	–	–	WE4117	–	–	3.7	10	–	–
WE2110	3.9	6	3.7	10	–	–	WE4140	–	–	–	–	4.4	10
WE2111	–	–	4.5	1	–	–	WE4141	–	–	–	–	4.7	7
WE3101	–	–	–	–	6.0	2	WE5107	–	–	3.5	13	–	–
WE3102	–	–	–	–	4.7	7							
Check1	3.7	8	3.4	14	–	–							
Check6	–	–	–	–	4.1	11							
Check9	3.9	6	4.0	4	5.2	5							
Check12	–	–	–	–	3.6	12							
Check16	–	–	–	–	3.1	13							
Mean	4.3	na‡	3.7	na	4.7	na							
LSD (0.05)	1.0	na	0.9	na	1.5	na							
CV, %	18.0	na	19.6	na	20.7	na							
No. of location	14	na	34	na	14	na							
Genotype signifiance	0.00	na	0.00	na	0.00	na							

† Mean grain yield.
‡ na, Not applicable.

crop to drought; and some farmers had zero yield. However, *DroughtTEGO* hybrids braced the drought with good performance and yield advantage of up to 70% compared with commercial checks.

On average, across the maize-growing counties in Kenya, the top five best hybrids were WE5213, WE4207, WE5205, WE4208, and WE2108 (Table 4). These hybrids yields ranged from 5.5 to 6.3 Mg ha^{-1}; 33 to 54% greater than the best commercial check and could be generally recommended to farmers. However, WE1101 ranked among the top 10 in all the agroecologies while WE3105 ranked among top 10 in almost all agroecologies, except lower eastern Kenya; and thus, both hybrids are more specifically adapted to these agroecologies. WE1101 was also the most preferred hybrid based on famers' rating in terms of whiteness of flour, stay green character after physiological maturity, milling quality, and good taste of ugali or roasted as green maize. These are important traits to consider in future maize improvement programs. These improved high-yielding and climate-smart *DroughtTEGO* hybrids identified in this study, should be promoted in Kenya to increase maize productivity and farmer livelihoods.

CONCLUSIONS

Maize remains a very important staple crop in SSA particularly in Kenya and its consumption will continue to increase due to population increase. Therefore, mitigation of maize productivity constraints using viable approaches in R4D cannot be overemphasized. Interventions through breeding of varieties resilient to drought is key to overcoming the constraint during water stress in the field to protect yields and ensure better livelihoods among smallholder farmers. *DroughtTEGO* hybrids improved for drought tolerance have shown the potential to help farmers to mitigate the effects of drought with yield advantage ranging from 17 to 19% in the South Rift Valley region to as high as 83 to 153% in Mt. Kenya region compared with the commercial hybrids popular in Kenya.

It is also important that the development of new improved varieties factor in farmers' preferred traits for successful adoption. Creation of awareness on the new hybrids by promotion and marketing through conducting large number of on-farm demonstration trials with field days as proven in this study, is key to driving adoption of new varieties. Adoption of high-yielding improved drought stress-tolerant maize hybrids by smallholder farmers can contribute to increased maize productivity and production in Kenya and other parts of SSA. Therefore, the adoption and scaling up of *DroughtTEGO* hybrids through deployment and commercialization in Kenya and other countries in SSA was recommended to mitigate drought in maize farming for better and stable yields.

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CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest.

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