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Research Article

Trait association and path analysis in drought tolerant tef (*Eragrostis tef*) genotypes

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Abstract

The goal of this research was to look at the genotypic and phenotypic associations of quantitative traits, as well as the direct and indirect effects of these traits on tef grain yield and use in national tef breeding programs. The research was carried out during the 2017 main cropping season in the drought-prone areas of Melkassa and Alem Tena in Ethiopia's Central Rift Valley. The experiment was laid out by a 7 × 7 simple lattice design, 42 drought-tolerant tef advanced lines, their parents (Dtt2, Dtt13, Quncho, and the cultivar Kaye Murri), two varieties (Tsedey and Simada) released for low moisture areas, and a local check were used. A positive genotypic association was found in approximately 60% of the total trait association. This positive correlation could be attributed to the presence of common genetic elements that influence the characters in the same way. Grain yield was positively and significantly correlated with above-ground biomass and harvest index at both the phenotypic and genotypic levels. The path coefficient analyses revealed that shoot biomass is the most important component trait determining grain yield, followed by harvest index. The current study found that using the traits identified as yield predictors in tef, a wide range of simultaneous improvements in grain yield could be achieved through selection.

Keywords: Correlation, Direct effect, Indirect effect, Tef, Path analysis

INTRODUCTION

Tef is grown throughout Ethiopia because it is the preferred grain for local consumption is highly valued by farmers and consumers and has the highest grain cost when compared to other cereals. It is resistant to a variety of biotic and abiotic stresses, making it a "low risk" crop for large-scale production Tef can grow in a variety of ecological conditions from sea level to 3000 meters above sea level (m.a.s.l). It is grown on over three million hectares of land each year accounting for roughly 30 percent of the total area and 20 percent of the gross grain production of cereals grown in the country (Debebe et al., 2012).

Nowadays, the crop is gaining global attention for its high nutritional, protein, and mineral content, as well as its gluten-free status Making it an alternative food for people suffering from celiac disease (Spaenij-Dekking et al., 2005); (Saturni et al., 2010). Despite its food, feed, and economic importance, tef productivity in the country is relatively low, yielding 1.85 tons ha^{-1}. The main yield-limiting factors in tef are a lack of cultivars that are resistant to low moisture stress, lodging, biotic and abiotic stress, and small seed size (Debebe et al., 2014).

Tef attains maturity relatively more quickly and shows the capacity for drought escape allowing a reasonable yield compared with sorghum, maize, and wheat (Kassie et al., 2013). However, grain yield reduction of 26%, 51% and 29% has been reported due to low moisture stress in tef (Wondewosen et al., 2012). The wide range of characteristic diversity in tef infers adequate opportunities for genetic improvement through either direct selection or intra-specific hybridization between parental lines with attractive characteristics (Assefa et al., 2002).

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Grain yield in tef, like other crops, is a complex character that is determined by various components and influenced by many other important yield contributing characters controlled by polygenes as well as environmental factors (Simmonds, 1962). Selection is an important part of a breeding program because it allows for the development of genotypes with high productivity in a given environment. However, because of its complexity, selecting for high yield is difficult. As a result, direct selection for yield could only make a small amount of progress over a long period of time. Indirect selection via yield components has proven to be more effective (Ford, 1964). This selection criterion considers the information on agronomic character interrelationships, their relationship with grain yield, and their direct influence on grain yield. Nonetheless, if the contribution of different characters to yield is quantified using path coefficient analysis, selecting for yield via highly correlated characters becomes simple (Assefa et al., 2011).

Determining the interrelationships between various agronomic characters and their direct and indirect effect on grain yield could provide useful information for crop breeders in improving crop productivity, as well as a prerequisite for planning a meaningful breeding program. The relationship between traits can be quantified using genotypic and/or phenotypic coefficients of correlation. Path coefficient analysis is used to divide the correlation coefficients into direct and indirect effects and to clarify the relationship between various morphological characteristics and grain yield (Singh & chaundhary, 1977).

The primary breeding goal of the tef improvement program is to increase grain yield. Direct selection based on crop yields, on the other hand, is frequently ineffective in breeding programs because yield is influenced by its component traits (Mustafa & Elsheikh, 2007). Because most economic traits, including yield, are polygenically controlled and heavily influenced by environmental factors, an understanding of inheritance and research into the relationship between yield and its components is required for developing an effective selection program for identifying high yielding varieties. This implies that it is critical to select for other traits indirectly in order to improve grain yield. Correlation between traits is used to determine whether selection for one trait will have an effect on another. Positive and significant correlation between traits can be the result of strong coupling linkage between their genes or the characters may be the result of pleiotropic genes that control these characters in the same direction (Kearsey & Pooni, 2020; Chanyalew, 2010; Yadav et al., 2013; Yadav et al., 2017).

There is little information available on trait accessions and path coefficient analysis aspects of tef, and there is a need to generate data on the interrelationships of yield and yield-related traits among tef genotypes. As a result, the purpose of this study was to assess the relationship between various agronomic traits and their direct and indirect effect on grain yield of drought-tolerant tef genotypes and their use in a national tef breeding program (Abraha et al., 2016).

MATERIALS AND METHODS

Experimental sites

A field experiment was conducted in the Central Rift Valley of Ethiopia at two locations Melkassa and Alem Tena, during the 2017 main cropping season. Melkassa research site is found at an altitude of 1620 m with latitude of 8° 24' N and longitude of 39°21' E. It is mean maximum and minimum temperature of 28.5°C and 16.6°C respectively. Alem Tena research site is found at an altitude of 12575m with latitude of 8°20' N and longitude of 38° 57' E. The mean maximum and minimum temperature of Alem Tena is 29.49°C and 15.42°C respectively. Both sites lies in similar agro-ecologies of the country both receive similar annual rainfall 591mm and 686mm, respectively (Nigus et al., 2016).

Experimental materials

Forty-nine genotypes, including 42 drought tolerant advanced lines, four parents of the advanced lines, two varieties, and a local check were used for this study. The seeds of all genotypes were obtained from Debre Zeit Agricultural Research Center (DZARC). The lines were previously developed by independent intercrossing among the parental lines Dtt2, Dtt13, Quncho/DZ-Cr-387 (RIL-355), and the cultivar Kaye Murri, which were also included in this study. The two varieties (namely, Tsedey and Simada) were released for low moisture areas. One local check was included from the respective (Jifar et al., 2015).

Experimental Design and Procedures

The experiment was laid out in a 7×7 simple lattice design. Each experimental plot was 1 m^2 (1m × 1m) and consisted of five rows spaced 20 cm apart. The distances between both incomplete blocks and plots within incomplete blocks were 1m, and that between replications was 1.5 m. The genotypes were allotted to plots at random within each replication. As per the research recommendations of 15 kg/ha, 1.5 g/plot of seeds were hand broadcasted along the surface of each row (Lenka & Mishra, 1973).

Data Collection

Five individual plants were selected randomly per plot, marked before panicle emergency, and used as a sample for some quantitative data collected. Data were recorded for days to seedling 50% emergence, days to 50% heading, days to 90% physiological maturity, grain filling period, plant height (cm), panicle length (cm), peduncle length (cm), culm length (cm), number of spikelets per panicle, numbers of primary panicle branches per the main shoot, number of florets per spikelet, number of total tillers per plant, number of fertile tillers per plant, lodging index (%), total above-ground biomass (kg/ha), grain yield (kg/ha), harvest index (%) and thousand-seed weight (g) (Lule & Mengistu, 2014).

Statistical data analysis

R software (3.5 versions) was used to analyses the genotypic and phenotypic correlation coefficients between all possible pairs of quantitative traits, as well as the direct and indirect effect of the independent variables on grain yield per plant at the genotypic and phenotypic levels (Sharma et al., 2001). The correlation coefficients (r) between pairs of quantitative traits were calculated using the method. The phenotypic and genotypic correlation coefficients between yield and yield related traits were estimated using phenotypic correlation coefficient and genotypic correlation coefficient (Al-Aysh et al., 2012).

Path coefficient analysis was performed for data combined across locations using the phenotypic and genotypic correlation coefficients between traits to determine the direct and indirect effects of yield-related traits on grain yield following (Dewey & Lu, 1959). The residual effect was calculated to determine how well the causal factors account for the variability of the dependent factor yield (Abraha et al., 2017).

RESULT AND DISCUSSION

Genotypic and phenotypic correlation coefficient

For combined locations, estimates of genotypic and phenotypic correlation coefficients between each pair of characters were investigated (Table 1). In most cases, the phenotypic correlation coefficients were smaller in magnitude than the genotypic correlation coefficients, indicating the presence of inherent genetic relationships among various characters and being fewer environments dependent. In this study, genotypic correlation coefficients were found to be greater in magnitude than phenotypic correlation coefficients in the majority of traits, indicating the presence of an inherent association between various characters, which is consistent with previous findings (Robertson et al., 1959).

Highly significant positive genotypic associations of grain yield were observed with above-ground biomass (rg=63) and harvest index (rg=49); while significant positive genotypic correlations were detected for grain yield with panicle length (rg=0.27). Similarly, highly significant positive phenotypic associations of grain yield were found for above-ground biomass (rp=65) and harvest index (rp=59). Moreover, days to physiological maturity (rp=0.15), grain filling period (rp=0.14), and panicle length (0.18) had positive significant associations with grain yield. The observed positive association of grain yield with above-ground biomass and harvest index showed that selection of these traits would enhance tef productivity. The positive correlations of tef yield with above-ground biomass and harvest index were reported in various previous studies (Piccinin, 2002).

Grain yield was negatively correlated with days to seedling emergence at the genotypic level (rg=-0.32). This implies that genotypes requiring long days for seedling emergence would be unsuitable for the study area. Despite the fact that lodging is known to cause tef yield losses and quality deterioration, the lodging index did not show a significant association ($P \geq 0.05$) with grain yield at both the genotypic and phenotypic levels. These findings contradict the previous findings of who reported a significant negative correlation of grain yield with lodging index, and those who reported a positive and highly significant correlation of grain yield with lodging index at both genotypic and phenotypic levels ($P < 0.01$) (Ketema et al., 1993).

Relationship of phenological traits with other traits

Days to physiological maturity (rg=0.72), plant height (rg=0.80), panicle length (rg=0.79), culm length (rg=0.71), number of primary panicle branches per main shoot (rg=0.75), number of spikelets per panicle (rg=0.65), and above-ground biomass (rg=0.66) all showed a highly significant positive genotypic association with days to heading. On the other hand, days to heading, had a significant negative genotypic relationship with days to seedling emergence, lodging index, total tillers per plant, fertile tillers per plant, and harvest index (Table 1). Similarly, Kebebew *et al.* (2002) and Tsion (2016) found a significant positive genotypic association between days to heading, days to physiological maturity, panicle length, and culm length (Memon et al., 2014).

Days to 50% heading had a significant positive phenotypic association with plant height (rp=0.60), panicle length (rp=0.61), culm length (rp=0.44), number of primary panicle branches per the main shoot (rp=0.35), number of spikelets per panicle (rp=0.30), above-ground biomass (rp=0.38), and thousand-seed weight (rp=0.15). Days to 50% heading, on the other hand, had a significant negative phenotypic relationship with days to emergence (rp=-0.46), lodging index (rp=-0.35), and harvest index (rp=-0.35).

Grain filling period had a significant positive genotypic association with peduncle length, number of total tiller per plant, and number of fertile tiller per plant. It had a significant positive phenotypic association with panicle length, number of primary panicle branches per main shoot, total tillers per plant, and fertile tillers per plant, above-ground biomass, and grain yield. However, grain filling period correlated negatively with culm length, peduncle length, number of spikelets per panicle, and number of florets per spikelet (Table 1).

Table 1. Estimates of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients for 18 traits of 49 tef genotypes over two locations.

Trait	DTE	DTH	DTM	GFP	PH	PL	CL	PDL	NSPP
DTE	**1.00**	-0.51**	-0.23	0.29*	-0.18	-0.23	-0.12	0.25	-0.15
DTH	-0.46**	**1.00**	0.72**	-0.18	0.80**	0.79**	0.71**	-0.14	0.65**
DTM	0.10	0.42**	**1.00**	0.55**	0.80**	0.85**	0.66**	0.12	0.61**
GFP	0.38**	-0.13	0.84**	**1.00**	0.17	0.24	0.09	0.34*	0.08
PH	-0.17*	0.60**	0.21**	-0.12	**1.00**	0.92**	0.94**	0.10	0.72**
PL	-0.02	0.61**	0.60**	0.29**	0.77**	**1.00**	0.74**	-0.02	0.72**
CL	-0.23**	0.44**	-0.09	-0.37**	0.90**	0.42**	**1.00**	0.19	0.63**
PDL	-0.06	-0.04	-0.19**	-0.19**	0.26**	-0.07	0.41**	**1.00**	-0.04
NSPP	-0.19**	0.35**	-0.01	-0.23**	0.46**	0.30**	0.45**	0.15*	**1.00**
PPBMS	0.17*	0.30**	0.52**	0.39**	0.10	0.44**	0.15*	0.35**	0.16*
NFPS	-0.14*	0.12	-0.14*	-0.22**	0.13	0.02	0.16*	0.07	0.30**
NTTPP	0.32**	-0.09	0.59**	0.71**	-0.32**	0.12	-0.53**	-0.28**	-0.30**
NFTPP	0.33**	-0.13	0.56**	0.69**	-0.30**	0.11	-0.49**	-0.27**	-0.31**
LI	0.07	-0.35**	-0.15*	0.04	-0.41**	-0.30**	-0.37**	-0.08	-0.23**
BY	-0.19**	0.38**	0.38**	0.19**	0.46**	0.53**	0.29**	-0.01	0.26**
GY	-0.13*	0.04	0.15*	0.14*	0.08	0.18*	-0.01	-0.05	0.03
HI	0.04	-0.35**	-0.20**	-0.01	-0.38**	-0.33**	-0.31**	-0.07	-0.22**
TSW	0.02	0.15*	0.19**	0.12	0.18*	0.19**	0.12	0.11	0.17*

Trait	PPBMS	NFPS	NTTPP	NFTPP	LI	BY	GY	HI
DTE	0.27	-0.08	0.01	0.07	0.15	-0.37**	-0.32*	0.04
DTH	0.75**	0.21	-0.28*	-0.37**	-0.55**	0.66**	0.13	-0.59**
DTM	0.47**	0.06	-0.02	-0.09	-0.53**	0.71**	0.11	-0.65**
GFP	0.23	-0.16	0.31*	0.32*	-0.08	0.21	0.01	-0.21
PH	0.67**	0.06	-0.28*	-0.33*	-0.57**	0.66**	0.09	-0.60**
PL	0.67**	0.04	-0.19	-0.26	-0.49**	0.75**	0.27*	-0.51**
CL	0.58**	0.07	-0.33*	-0.34*	-0.57**	0.49**	-0.05	-0.61**
PDL	0.17	-0.16	0.16	0.10	-0.21	-0.03	-0.17	-0.18
NSPP	0.71**	0.27	-0.07	-0.08	-0.48**	0.59**	0.22	-0.41**
PPBMS	**1.00**	0.32*	-0.10	-0.19	-0.46**	0.54**	0.20	-0.37**
NFPS	-0.03	**1.00**	-0.19	-0.19	-0.09	0.16	0.13	0.01
NTTPP	0.41**	-0.25**	**1.00**	0.93**	0.17	-0.05	0.13	0.21
NFTPP	0.38**	-0.28**	0.96**	**1.00**	0.22	-0.08	0.13	0.25
LI	-0.10	-0.10	0.12	0.15*	**1.00**	-0.28*	0.22	0.61**
BY	0.29**	0.12	0.04	0.03	-0.17*	**1.00**	0.63**	-0.36*
GY	0.09	0.06	0.09	0.09	0.05	0.65**	**1.00**	0.49**
HI	-0.17*	-0.04	0.07	0.09	0.25**	-0.22**	0.59**	**1.00**
TSW	0.03	0.07	0.05	0.04	-0.15*	0.15*	0.04	-0.1

, * *Significant at 0.05 and 0.01 probability level respectively, DTE= days to emergency, DTH =days to heading, DTM = days to physiological maturity, GFP = grain filling period, PH= Plant height, PL=panicle length, CL= culm length, PDL= peduncle length, NSPP=number of spikelet's per panicle, PPBMS = number of primary panicle branches per main shoot, NFPS =number of florets per spikelet, NTTPP= number of total tillers per plant, NFTPP= number of fertile tillers per plant, LI= lodging index, BY=biomass yield, GY= grain yield, HI = harvest index and TSW= thousand-seed weight.*

Relationships of lodging with other traits

Lodging index (rp=0.61) showed a significant positive genotypic association with the harvest index only. Plant height, panicle length, culm length, number of primary panicle branches per main shoot, number of spikelets per panicle, above-ground biomass, and thousand-seed weight, on the other hand, showed a negative significant genotypic correlation (Table 1). Lodging index was also found to have a positive significant phenotypic relationship with the number of fertile tillers per plant (rp=0.15) and harvest index (rp=0.25). On the other hand, lodging index depicted a negative significant phenotypic relationship with days to heading, days to physiological maturity, plant height, panicle length and culm length, number of spikelets per panicle, above-ground biomass and thousand-seed weight. This is in line with the findings of who reported that lodging index showed a positive and significant correlation at the genotypic and phenotypic level with harvest index and negative significant relationship with panicle length, culm length and above ground-biomass.

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Path coefficient analysis

Path coefficient analysis was used to identify important yield attributes by estimating the direct effects of traits contributing to grain yield and separating the direct from the indirect effects via other related traits by partitioning the correlation coefficient and determining the relative importance of different characters as selection criteria. Grain yield was regarded as the consequential character because it was the complex outcome of various traits. In this study, four and six characters were selected as casual variables for genotypic and phenotypic correlations, respectively, because they have a significant relationship with grain yield. The residual effect was not significantly high at both the genotypic and phenotypic levels, indicating that almost all traits that influenced grain yield were taken into account. Tables 2 and 3 show the genotypic and phenotypic direct and indirect effects of selected traits on grain yield.

Genotypic direct and indirect effects of various traits on grain yield

Genotypic path coefficient analysis showed that above ground-biomass (0.936) and harvest index (0.816) showed a strong direct positive effect on grain yield. However, days to seedling emergence (-0.009) and panicle length (-0.022) had a weak negative direct effect on grain yield (Table 2). This indicated that emphasis should be given to the above-ground-biomass and harvest index in the process of selection as these traits are helpful for direct selection. Previously, (Habtamu et al., 2011) reported bio mass yield and harvest index exhibiting high direct effects on grain yield. The authors suggested that selecting for these traits indirectly helps improve grain yield. Similarly, reported that harvest index and above-ground biomass had a strong direct effect and positive correlation with grain yield in tef landraces (Assefa et al., 2015).

Days to seedling emergence had a positive indirect effect on grain yield through panicle length and harvest index. While days to seedling emergence had a negative indirect effect through above-ground biomass. Panicle length strong positive indirect effects (0.709) and negative indirect effects (-0.420) *via* above-ground biomass and harvest index with grain yield, respectively. Above-ground biomass had a negative indirect effect through harvest index (Table 2). Alike to current findings, reported that at the genotypic level, panicle length exerted weak and negative direct effects on grain yield in both stressed and non-stressed environments. Above-ground biomass and harvest index can be considered as good contributors to grain yield and suggesting that they are important traits for selection in a breeding program for higher grain yield of tef. However, traits with negative indirect effects through above-ground biomass need to be managed during selection because the selection of traits might have reducing effect on yield (Bultosa et al., 2002).

Days to seedling emergence showed relatively weak positive and/or negative direct and indirect genotypic effects on grain yield through above-ground biomass, harvest index and panicle length. Generally, trait association between yield and yield components in this particular study indicated the various magnitude of association which can be carefully looked into while exploiting in selection to improve traits of interest in tef breeding (Boac & Bale Robe, 2012).

Table 2. Estimates of direct (bold diagonal) and indirect effect (off-diagonal) at the genotypic level of four traits on grain yield in 49 tef genotypes tested in Central Rift Valley of Ethiopia 2017.

Trait	DTE	PL	BY	HI	rg
DTE	**-0.009**	0.005	-0.346	0.034	-0.315*
PL	0.002	**-0.022**	0.709	-0.420	0.269*
BY	0.003	-0.016	**0.936**	-0.294	0.629**
HI	0.000	0.011	-0.338	**0.816**	0.489**

Note: *** and * indicate highly significant at 1% and significant at 5% probability levels respectively. rg: genotypic correlations with the grain yield, DTE= days to emergency, DTM = days to physiological maturity, GFP = grain filling period, PL=panicle length, BY=biomass yield, HI = harvest index and Residual effect =0.170.*

Table 3. Estimates of direct (bold diagonal) and indirect effect (off-diagonal) at the phenotypic level of six traits on grain yield in 49 tef genotypes tested in Central Rift Valley of Ethiopia 2017.

Trait	DTE	DTM	GFP	PL	BY	HI	rp
DTE	**-0.0006**	0.0001	-0.0038	0.0001	-0.1573	0.0318	-0.1296*
DTM	-0.0001	**0.0006**	-0.0084	-0.0027	0.3119	-0.1531	0.1482*
GFP	-0.0002	0.0005	**-0.0099**	-0.0013	0.1560	-0.0091	0.1359*
PL	0.0000	0.0003	-0.0029	**-0.0046**	0.4376	-0.2505	0.1800*
BY	0.0001	0.0002	-0.0019	-0.0024	**0.8193**	-0.1652	0.6500**
HI	0.0000	-0.0001	0.0001	0.0015	-0.1770	**0.7648**	0.5893**

Note: *** and * indicate highly significant at 1% and significant at 5% probability level respectively. rp: phenotypic correlations with the grain yield, DTE= days to emergency, DTM = days to physiological maturity, GFP = grain filling period, PL=panicle length, BY=biomass yield, HI = harvest index and Residual effect =0.196.*

Phenotypic direct and indirect effects of various traits on grain yield

Above-ground-biomass (0.819) and harvest index (0.765) exerted strong positive direct phenotypic effects on grain yield, while days to physiological maturity (0.0006) had a weak positive phenotypic direct effect on grain yield. However, days to seedling emergence (-0.0006), grain filling period (-0.0099) and panicle length (-0.0046) had a negligible negative phenotypic direct effect on grain yield (Table 3). This showed that the strong correlations of above-ground biomass and harvest index with grain yield were largely due to the direct effect of the traits. Therefore, direct selection of the high-performing genotypes for these traits will improve the mean grain yield of the selected genotypes. In agreement with the present results also obtained large direct effects of harvest index (0.617) on tef grain yield. Likewise, reported high direct effect of above ground-biomass on grain yield.

The magnitudes of the direct effects exerted on grain yield by above-ground biomass and harvest index were higher than their corresponding phenotypic correlation coefficients with grain yield. This justifies that the correlation explains the true relationships and selection through this trait will be effective.

The indirect effects of all traits on grain yield *via* other traits except through above-ground biomass and harvest index were small and negligible. However, each of the components of grain yield showed considerable indirect effects *via* other traits like above-ground biomass and harvest index in both negative and positive directions. Similar results were found which showed that indirect effects of traits on grain yield were exerted *via* above-ground biomass and harvest index in both negative and positive directions.

There was a zero indirect effect of some traits on grain yield. These indicate that the correlations of such traits might be weak. Reported that panicle length exerted negligible direct effect due to counter-balancing of indirect effects through other traits. As reported, the number of leaves per plant had zero percent of contribution on grain yield in cowpea.

CONCLUSION

Genotypic correlations were found to be higher in magnitude than that of phenotypic correlations for the majority of the traits studied. This indicated that genetic factors played a major role in these associations among the majority of the traits. Grain yield was found to be positively and significantly correlated with total above-ground biomass and harvest index both at the phenotypic and genotypic levels. The path coefficient analyses revealed that the superseding component trait determining grain yield is above-ground biomass followed by harvest index. Moreover, the magnitude's direct effects were similar to the magnitudes of correlations implying that the correlations reflect the relationship and the importance of these traits in yield improvement. The minimum value of the direct and indirect phenotypic effect of the majority of polygenic traits on grain yield per plant observed in the present study indicated that genetic manipulations of tef genotypes for several quantitative characters are more important to improve the productivity of tef than management practices.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

ETHICS APPROVAL

Not applicable.

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