Breeding cool-season forage grasses for a warming climate

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Abstract
In many parts of the world, changing climatic conditions are resulting in increased temperatures and more variable precipitation, intensifying the duration and severity of drought, especially in summer. Warming climate is considered one reason for the increasing failure of traditional, summer-active cool-season perennial grasses at the margin of their zone of adaptation in naturally C_4 grass-dominated ecosystems of the Southern Great Plains of the USA. Two cool-season perennial forage grasses orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.) are of major economic and ecological importance in these regions. In 2008, we initiated a breeding program of summer-dormant (Mediterranean) cool-season perennial grasses originating from the Mediterranean Basin, including tall fescue, orchardgrass, and perennial ryegrass. In this publication, we present breeding history and morphological characteristics of cv. Yonatan (also known under research name TAL-02), a new cultivar of summer-dormant tall fescue. Recurrent selection cycles were conducted to develop cv. Yonatan during 2007-2010. Evaluations were performed on several locations across north Texas, Australia and New Zealand during 2015-2020. Yonatan tall fescue has improved forage production and persistence compared with check cultivars Flecha and Chisholm. It also differs from them in terms of wider leaves, earlier maturity, and development of a bulbous storage organ at the base of the tiller. Yonatan is adapted to changing climatic conditions in the Southern Great Plains of the USA, Australia, and New Zealand.

Introduction
Since the early 2000's, changing climatic conditions in the Southern Great Plains (SGP) of the USA have been characterized by rising temperatures, declining precipitation, abrupt patterns of precipitation and frequent, severe droughts (Nielsen-Gammon 2011). These new weather patterns affect timely planting and establishment of winter wheat (*Triticum aestivum* L), the major annual cool-season forage in this region. Traditional, continental types of improved cool-season forage grasses introduced to SGP in the 70's cannot cope anymore with altered climatic conditions and have massively failed (Belesky and Malinowski 2016). Texas A&M AgriLife Research initiated research on summer-dormant tall fescue as an alternative cool-season forage for SGP in 2000. In 2008, Grasslands Innovation became a partner in this breeding program contributing germplasm, knowledge, and international testing sites. Our long-term research has demonstrated that summer-dormant tall fescue is well adapted to environments of the SGP and tolerant of both increasing temperatures and severe summer droughts (Norton et al. 2016). In this publication, we present the breeding history and major characteristics of Yonatan, a novel cultivar of summer-dormant tall fescue.

Methods
Yonatan is a summer-dormant, Mediterranean type of tall fescue selected from the base accession "TAMUS-2688" that originated from the Golan Heights, Israel (32.55º N; 35.46º E; elevation 515 m; annual precipitation 680 mm). This tall fescue accession occurs in its native environment in rocky soils on foothills and hill slopes.

Yonatan is a product of a planned breeding program conducted by the breeders at Texas A&M AgriLife Research and Extension Center in Vernon, TX (34.09° N, 99.17° W; elevation 361 m; annual precipitation 711 mm) in collaboration with Grasslands Innovation/PGG Wrightson Seed Ltd., New Zealand. The symbiotic *Neotyphodium* ssp. endophyte present in the "TAMUS-2688" accession was eliminated by treating seedlings with propiconazole fungicide and testing plants for endophyte infection 6 months after the treatment (Saiga et al. 2003). The new generation was 100% free of endophyte infection. Four cycles of recurrent selection (out of 1000 plants each time) were conducted during 2007-2010. Plants were selected for wide leaves, large tiller number and size, high seed yield, and tolerance to leaf rust *Puccinia coronata,* a common fungal disease of grasses in Texas.

In autumn 2010, seedlings of the best 50 plants selected from the 4th selection cycle were planted at Vashti, TX (33.55° N, 98.04° W; elevation 330 m; annual precipitation 863 mm) and exposed to grazing and weed competition stress, and at Vernon, TX exposed to mechanical defoliation at 7.5 or 15 cm height and weed competition stress. The half-sib families were planted in rows, spaced 30 cm apart, at 25 plants per row spaced 15 cm apart, replicated four times. Winter weeds were predominantly bromegrass (*Bromus* sp.) at Vernon and bromegrass and annual ryegrass (*Lolium multiflorum* Lam.) at Vashti. Summer weeds were represented by crabgrass (*Digitaria* sp.) and careless weeds (*Amaranthus* sp.) at Vernon, and crabgrass and Johnsongrass (*Sorghum halepense* L.) at Vashti. The soil type at Vernon had pH of 7.2, while the soil pH at Vashti was 4.8. This allowed for selection of genotypes adapted to a wide range of soil pH. No fertilization or irrigation was applied during the screening trial (autumn 2010 – summer 2012).

In spring 2012, 30 plants with desirable traits in each treatment and location were marked (180 plants in total). These plants were re-planted on an isolated location at Chillicothe, TX in autumn 2012 in a pollination block. Plants with undesirable traits were eliminated prior to anthesis. In June 2013, pre-nucleus seed was collected and bulked. One additional cycle of selection for leaf rust resistance was made in New Zealand in 2014 and a nucleus seed crop of this selection produced in 2015.

Morphological traits were measured on 49 plants of each entry spaced at 45 cm distances and replicated 4 times. These plants were raised from seeds in a greenhouse in September 2017 and transplanted in the field in October 2017. Measurements were carried out in spring 2018.

Agronomic evaluations were planted with a Wintersteiger precision planter at 15 kg ha^{-1} seeding rate and 23 cm distance between rows in 10 or 15 m length strips, depending on year and location, in October each year during multiple testing periods and locations across northern Texas. Forage samples were harvested at 7.5-cm height from an area of 0.5 m^2 in the central part of each strip every time the sward was at least 30 cm tall. Plants were fertilized with 30 kg ha^{-1} N in March and November in each growing season. Agronomic evaluation experiments lasted usually for three growing seasons.

Data were subject to Procedure Mixed of SAS, where grass entry, defoliation height, and growing season were considered fixed effects, and replication was considered a random effect.

Results and Discussion

Yonatan has significantly longer and wider leaves than other summer-dormant tall fescue cultivars, but narrower than summer-active cv. Jesup (Table 1). Tillers of Yonatan are shorter than those of Flecha and Prosper. Flag leaf height is similar to Chisholm and Flecha, but shorter than Jesup and Prosper. Panicle length of Yonatan is shorter than that of other cultivars, except for Chisholm. The 1000 seed weight of Yonatan is similar to that of Chisholm, greater than that of Flecha and lighter than 1000 seed weight of Jesup and Prosper.

Table 1. Morphological characteristics of tall fescue cv. Yonatan and check cvs. Jesup (summer-active), and Chisholm, Flecha and Prosper (summer-dormant). Means with the same letters are not significantly different at p = 0.05.

Cultivar	Leaf length (cm)	Leaf width (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Tiller height (cm)	Flag leaf height (cm)	Panicle length (cm)	1000 seed weight (g)
Yonatan	25.2 A	0.66 B	23.6 B	0.49 B	126 C	48.0 C	34.3 D	1.99 C
Jesup	24.7 A	0.74 A	23.0 B	0.68 A	129 CB	66.8 A	36.1 BC	2.69 A
Chisholm	22.3 B	0.34 C	24.0 AB	0.40 C	128 CB	48.0 C	35.0 CD	2.00 C
Flecha	21.8 B	0.32 C	21.7 C	0.41 C	130 B	48.3 C	36.6 AB	1.79 D
Prosper	21.5 B	0.33 C	24.7 A	0.38 D	134 A	54.1 B	37.7 A	2.23 B
Mean	23.1	0.48	23.4	0.47	129	53	35.9	2.14
Standard error	0.31	0.01	0.36	0.01	1.19	0.82	0.47	0.07

Yonatan produces a higher seasonal forage dry matter (DM) (Fig. 1) and more forage in early spring (data not shown) than other summer-dormant tall fescue cultivars. Because of its earlier maturity (Fig. 2) and higher summer dormancy score (Norton et al., 2008), Yonatan becomes dormant earlier than other tall fescue cultivars (Fig. 3).

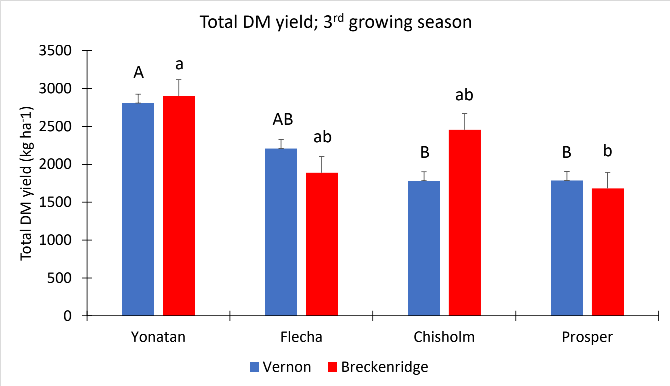

Fig. 1. Seasonal forage dry matter (DM) productivity of Yonatan, Flecha, Chisholm, and Prosper summer-dormant tall fescue cultivars at Vernon and Breckenridge during the 3rd growing season (2018). Means with the same capital (Vernon) or common (Breckenridge) letters are not significantly different. Bars indicate 1 standard error.

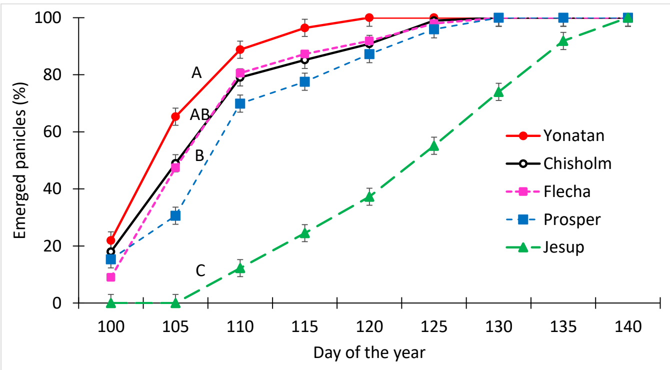

Fig. 2. Percentage of emerged panicles of Yonatan Flecha, Chisholm, and Prosper (summer-dormant), and Jessup (summer-active) tall fescue cultivars at Vernon, TX during 2019. Regression coefficients of slopes with the same letters are not significantly different. Bars indicate ±1 standard error.

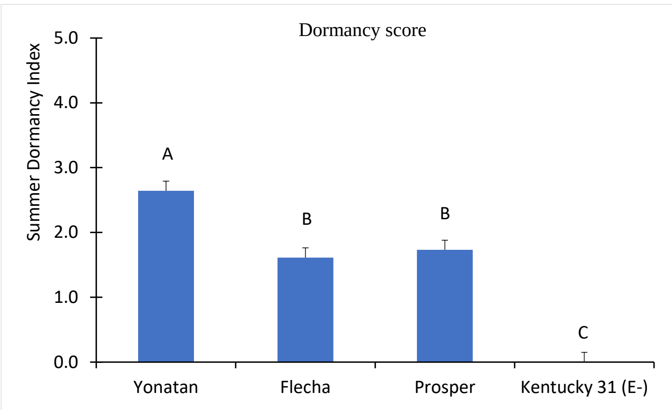

Fig. 3. Dormancy scores of Yonatan and Flecha and Prosper (summer-dormant), and summer-active Kentucky 31 (endophyte-free) tall fescue cultivars under non-limiting soil water content in a greenhouse study. Means with the same letters are not significantly different. Bars indicate 1 standard error.

In contrast to other tall fescue cultivars, Yonatan develops bulbous structures at the basal section of a tiller in spring (Fig. 4). These structures serve most likely as storage organs and may contribute to a very high persistence of Yonatan under hot and dry conditions, similar as for other summer-dormant grasses (Ofir and Kigel 2003).

Fig. 4. Storage organ at the basal section of a tiller of Yonatan (left) and lack of such organ in Flecha (right) summer-dormant tall fescue.

Conclusions and/or Implications

Traditional, summer-active (continental) types of cool-season perennial forage grasses are not adapted to quickly progressing changes in climatic patterns in the SGP of the USA. Areas with Mediterranean-like climate tend to encroach to the southern limits of historically temperate environments at about 44° to 46° N, rapidly limiting summer forage production (Lelièvre and Volaire, 2009). In environments of the SGP, summer-dormant cool-season perennial grasses have been proven persistent and adapted to current climatic conditions and can complement or replace forage availability from wheat pastures during autumn-spring (cool) grazing season. Grazing systems based on summer-dormant tall fescue cultivars may provide 519 grazing days ha^{-1}, 0.76 kg d^{-1} average daily gain, 395 kg ha^{-1} total gain, and positive net returns of \$383 ha^{-1} (Trammell et al. 2018).

The summer dormancy trait may be one of the best options to match cool-season forage grass production with changing patterns of precipitation in semiarid environments at latitudes 35° to 40° N and S, including California and the SGP of the United States, and environments in Australia, Argentina, and the Mediterranean Basin. Yonatan is one of several summer-dormant tall fescue cultivars with improved forage productivity and persistence currently being developed by Texas A&M AgriLife Research in collaboration with Grasslands Innovation and PGG Wrightson Seeds Ltd. It has been commercialized by Turner Seed Co., Breckenridge, TX and is expected to be available on the U.S. market in 2024.

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