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An Investigation of Trait Prioritization in Turfgrass Breeding Programs

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***Abstract*. The development and evaluation of new turfgrass cultivars require considerable resources. A systematic understanding of the breeders' and distributors' trait selection behavior can provide a basis for making adjustments and improvements based on industry needs and thus accelerate the breeding process and make it more efficient. The objective of this study is to investigate the selection priorities for turfgrass traits and identify the most influential factors affecting turfgrass breeders' and distributors' likelihood of selecting turfgrass traits. Results show that the most important trait clusters for both breeders and distributors were abiotic stress resistance and growth characteristics. Breeders were more likely than distributors to select appearance traits when setting trait priorities. Program characteristics such as program size, education level, and being a male respondent had positive effects on the reported likelihood of selecting studied turfgrass traits, and these effects varied for different trait clusters.**

There has been a long history for turfgrass breeding programs to evaluate, develop, and introduce turfgrass cultivars with superior traits for use on lawns, sports fields, parks, roadsides, and other landscapes. Turfgrass breeding, like any other product development activities, determines the inherent physical characteristics of the turfgrass cultivar and creates value for stakeholders in the supply chain (Solomon and Stuart, 2003). In the past decades, various turfgrass species have been developed and evaluated for pest and disease resistance (Cisar, 2010; Watkins et al., 2014), climate region adaption (Mintenko et al., 2002), and drought tolerance (Johnson, 2008), and reduced nitrogen requirements (Bonos and Huff, 2013; Johnson, 2008; Watkins et al., 2014).

The development and evaluation of new turfgrass cultivars require considerable financial inputs, along with technical knowledge, labor, and time resources. Therefore, it is important to understand which turfgrass traits are most important and have high priority from both breeders' and seed distributors' perspectives. A systemic understanding of the breeders' and distributors' trait selection behavior can provide a basis for making adjustments and improvements based on industry needs and thus accelerate the breeding process and make it more efficient. Although many studies have evaluated the performances of different turfgrass cultivars, little is known about how turfgrass breeding programs determine trait selection priorities. In practice, turfgrass breeders and distributors (market intermediates who sell turfgrass seeds) determine trait priorities based on their own experiences and insights gained from direct and indirect interactions with industry stakeholders such as producers. Nevertheless, because all parties along the supply chain (breeders, growers/producers, distributors, and consumers) play significant roles in the success of new and existing turfgrass cultivars, it is important to understand how breeders and distributors prioritize turfgrass traits and which parties affect the likelihood of turfgrass trait selection in the breeding programs.

Only a few studies have investigated the trait selection process of plant breeding programs. In 1996, Frey (1996) conducted a national survey to investigate the size of public and private plant breeding programs in the United States. The study found that a total of 2241 science person years were devoted to plant breeding, with only 55 science person years devoted to the lawn and turfgrass crop categories. Frey (1996) also found that ryegrass and bluegrasses were the turfgrass species with the most breeding effort. Gallardo et al. (2012) conducted a survey of breeders of Rosaceae species in the United States and Canada and found that consumer-driven forces positively affect the likelihood of selection for traits more than producer forces.

To our knowledge, no literature exists to investigate how turfgrass breeders and distributors prioritize turfgrass traits in their breeding or distributing programs. The specific objective of this study is to investigate the selection priorities for cool-season turfgrass traits and identify the most important factors that influence cool-season turfgrass breeders' and distributors' likelihood of selecting turfgrass traits. We include both cool-season turfgrass breeders and distributors because they play significant roles in determining turfgrass trait priorities. Yet, their roles are also slightly different in that distributors must make decisions about which product to sell based on which cultivars the breeders develop. We further compare the differences in breeders' and distributors' trait priorities and how various parties or factors affect their behaviors in different ways.

Methods

Data description. In May 2016, we distributed a comprehensive online survey to 238 U.S. cool-season turfgrass breeders and distributors to investigate their trait selection behavior. We selected breeders based on their

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membership in the Turfgrass Breeders Association and identified seed distributors by searching online for cool-season turfgrass seed suppliers in the northern United States. In total, we obtained 54 responses, representing a 22.7% response rate. Several were incomplete and excluded from this study, which left us with 11 complete responses from turfgrass breeders and 34 responses from seed distributors.

Three sets of questions were included in the survey. The first set of questions included background information such as the program size and affiliation (university, government, or private company), years of working experience as a breeder or distributor, and respondents' gender and education level. The survey also asked questions about the turfgrass species the breeders or distributors were breeding or distributing, their targeted regions, and major uses of their turfgrasses. Questions about how interested parties (such as consumers, producers/growers, wholesalers, marketing companies, etc.) influenced their breeding or distributing decisions were included in the second section. Breeders and distributors were asked to rate the importance of factors affecting the selection of turfgrass priorities (using a 0 to 10 continuous scale, 0 = very unimportant and 10 = very important). The third set contained questions regarding breeders' and distributors' selection of important turfgrass traits and the likelihood that breeders select traits to work on or distributors select cultivars with certain traits (using a 0 to 100 scale, 0 = lowest likelihood and 100 = highest likelihood). We selected the 30 turfgrass traits in our survey based on presurvey interviews that were conducted with five turfgrass breeders. A large number of traits made it difficult to compare relative importance; therefore, we aggregated individual traits as trait clusters based on the trait similarities and differences (Table 1). A copy of the survey is available on request.

Empirical model. We employed a double-bounded Tobit model to investigate the factors significantly influencing breeders' and distributors' likelihood of trait selection. The observed dependent variables were the likelihood of selecting the trait clusters (the likelihood range from 0 to 100, left-censored at 0 and right-censored at 100). The observed dependent variable, Y, is censored. The model assumed there is an uncensored latent variable (Y^*). The unobserved dependent variable Y^* is expressed as a function of a vector of independent variables X by the following specification:

$$Y^* = X\beta + \varepsilon; \varepsilon \sim \text{Normal}(0, \sigma^2)$$

where β is the vector of unknown coefficients and ε is the error term that is assumed to follow a normal distribution with zero mean and standard deviation of σ. The observed dependent variable is

$$Y = \max(0, Y^*) \text{ and } Y = \min(Y^*, 100)$$

where the independent variable vector X includes information on program characteristics such as (1) the importance of interested parties in influencing breeders' or distributors' trait priority; (2) target geographical regions where grass seeds would be produced and grasses would be used; (3) breeders' and distributors' background information such as years of experience working as breeders and distributors in the turfgrass industry, program size, respondents' education level, and gender. The models were estimated using the TOBIT procedure in STATA.

Table 1. Individual turfgrass traits included in each trait cluster.

Appearance[z]	Disease and pest resistance[z]	Abiotic stress resistance[z]	Growth characteristics[z]
Color—light	Disease resistance—dollar spot	Salt tolerance for low quality water/de-icing conditions	Aggressiveness
Color—dark	Disease resistance—brown patch	Drought tolerance	Nitrogen use efficiency
Finer leaf texture	Disease resistance—snow mold	Summer performance	Natural tolerance to glyphosate
Turf density	Disease resistance—summer patch	Heat stress tolerance	Quick germination
	Disease resistance—leaf spot	Wear and traffic tolerance	Germination reliability
	Disease resistance—crown and stem rust	Shade tolerance	Rapid tillering
	Disease resistance—other	Low mowing height tolerance	Slower vertical growth rate
	Insect resistance	Low fertilizer requirements	Seed yield
	Allelopathy (reduce weeds through root exudates)		
	Endophyte infection		

[z]The name of each cluster (appearance, disease and pest resistance, abiotic stress resistance, and growth characteristics) is listed in the head of this table; traits included in each cluster are listed in columns.

Table 2. Summary statistics of the background information of surveyed U.S. turfgrass breeders and distributors (n = 45).

		Breeders (n = 11)		Distributors (n = 34)	
Variables	Description	Mean	(SD)	Mean	(SD)
Male	1 if the respondent is male; 0 otherwise	0.73	(0.47)	0.94	(0.24)
Work years	Number of years breeder or distributor professional involved in the turfgrass industry	19.20	(9.29)	19.79	(11.35)
Program size	Size of the program in terms of number of full-time equivalent staff.	5.91	(4.48)	22.62	(45.21)
Education[z]	The highest level of education 1 = Some high school; 2 = High school degree; 3 = Some college; 4 = Bachelor's degree; 5 = Master's degree; 6 = PhD degree	4.73	(1.01)	3.91	(0.67)
West	1 if the target region of breeding program or the distributors is the western United States; 0 otherwise	0.82	(0.40)	0.32	(0.47)
Midwest	1 if the target region of breeding program or the distributors is the Midwestern United States; 0 otherwise	0.82	(0.40)	0.71	(0.46)
Northeast	1 if the target region of breeding program or the distributors is the northeastern United States; 0 otherwise	0.91	(0.30)	0.29	(0.46)
South	1 if the target region of breeding program or the distributors is the southern United States; 0 otherwise	0.82	(0.40)	0.24	(0.43)
Canada	1 if the target region of breeding program or the distributors is Canada; 0 otherwise	0.64	(0.50)	0.15	(0.36)
Importance of interested parties that influence setting of priorities (0 = very unimportant, 10 = very important)					
Consumers[y]		8.55	(1.13)	8.47	(1.83)
Producers/growers[y]		8.91	(0.94)	6.75	(2.74)
Wholesalers[y]		6.27	(2.80)	6.00	(3.01)
Marketing companies[y]		5.88	(3.00)	4.14	(2.22)
Sales staff needs[y]		6.50	(3.02)	6.44	(2.39)

[z]The highest level of education was a category variable. The midpoints in each category were used to convert education level to continuous variables.
[y]The importance level of interested parties was rated by respondents in the range of 0 to 10.

Results and Discussion

Summary statistics. Table 1 presents the four trait clusters used in this study: appearance, disease and pest resistance, abiotic stress resistance, and growth characteristics. The traits included in each cluster are detailed in Table 1.

Table 2 presents the summary statistics of the background information for breeder and distributor respondents. Most of the surveyed turfgrass breeders and turfgrass seed distributors were male. The average years of experience for both breeders and distributors were 19–20 years. The median years of experience were 19 for breeders and 17.5 for distributors. The program sizes in terms of full-time equivalent staff were six persons for breeders (in the range of 2–14 persons) and 23 persons for distributors (in the range of 1–239 persons). The average education level for breeders was a master's degree, whereas the distributors on average had a bachelor's degree. Most of the breeders considered the Northeast, the West, the Midwest, and the South as the target production regions. Distributors considered the Midwest, the West, the Northeast, and the South as the target regions.

The summary statistics for ratings of interested parties are also listed in Table 2. For breeders, the most important parties influencing their priority settings included producers/growers and consumers, followed by sales staff needs and wholesalers. These results were consistent with the previous research findings on the North American Rosaceous fruit breeding programs (Gallardo et al., 2012). When breeders set trait priorities, they considered the two ends of the supply chain (producer/growers and the consumers) as the most important parties. Distributors, on the other hand, considered consumers as the most important party, followed by producer/growers, wholesalers, and sales staff needs.

Table 3. Summary statistics for the selection likelihood of trait clusters by U.S. turfgrass breeders and distributors.

	All respondents (n = 45)		Breeders (n = 11)		Distributors (n = 34)	
Trait clusters	Mean[z]	(SD)	Mean[z]	(SD)	Mean[z]	(SD)
Appearance	58.32	(18.61)	67.79	(17.02)	55.36	(18.33)
Disease and pest resistance	57.27	(23.24)	59.86	(27.28)	56.46	(22.26)
Abiotic stress resistance	68.03	(18.79)	69.90	(18.35)	67.46	(19.17)
Growth characteristics	65.04	(18.27)	70.51	(22.82)	63.38	(16.72)

[z]This table shows the mean likelihood levels of selecting the trait clusters.

Table 4. Pairwise comparison using pairwise t tests for likelihood of selection of trait clusters by U.S. turfgrass breeders and distributors.

Comparison		t statistics[z]	P value
Appearance	Disease and pests resistance	3.65	0.0003
	Abiotic stress resistance	–26.49	0.0000
	Growth characteristics	–13.19	0.0000
Disease and pest resistance	Abiotic stress resistance	–23.99	0.0000
	Growth characteristics	–19.14	0.0000
Abiotic stress resistance	Growth characteristics	7.48	0.0000

[z]The t statistics values indicate the differences in the means of selection likelihood between different trait groups. A positive value indicates the first trait cluster is rated higher, whereas a negative value indicates the first trait is rated with lower likelihood of selection. For example, the t statistics for appearance, disease and pest resistance pair, 3.65, indicates that the likelihood of selecting appearance traits is higher than the likelihood of selecting disease and pest resistance traits. The t statistics for appearance–abiotic resistance pair, –26.49, indicates that the likelihood of selecting appearance traits is lower than the likelihood of selecting abiotic stress resistance traits. The small P values indicate all the comparison pairs are significantly different from each other at 1% level.

Table 5. U.S. turfgrass breeder and distributor selection likelihood for individual traits within each trait cluster.

	All respondents (n = 45)		Breeders (n = 11)		Distributors (n = 34)	
	Mean[z]	(SD)	Mean[z]	(SD)	Mean[z]	(SD)
Appearance						
Color—light	25.76	(24.71)	33.63	(29.18)	22.76	(22.86)
Color—dark	65.44	(26.64)	78.70	(18.83)	60.86	(27.66)
Finer leaf texture	60.70	(25.31)	83.71	(15.49)	54.50	(23.96)
Turf density	69.59	(20.91)	80.00	(16.09)	66.47	(21.39)
Disease and pest resistance						
Disease resistance—dollar spot	62.03	(31.72)	48.38	(35.31)	65.93	(30.16)
Disease resistance—brown patch	65.03	(33.19)	69.56	(38.87)	63.46	(31.70)
Disease resistance—snow mold	53.31	(30.04)	57.33	(38.27)	52.48	(28.81)
Disease resistance—summer patch	55.77	(27.79)	60.63	(28.37)	54.33	(28.00)
Disease resistance—leaf spot	62.88	(28.64)	83.29	(16.20)	57.38	(28.97)
Disease resistance—crown and stem rust	62.35	(31.02)	86.89	(19.04)	54.46	(30.17)
Disease resistance—other	43.17	(28.72)	48.33	(41.93)	42.43	(27.72)
Insect resistance	50.45	(28.32)	47.33	(34.63)	51.15	(27.46)
Allelopathy (reduce weeds through root exudates)	48.83	(25.18)	32.50	(26.30)	51.35	(24.56)
Endophyte infection	52.90	(33.94)	88.67	(13.06)	44.32	(31.75)
Abiotic stress resistance						
Salt tolerance for low quality water/de-icing conditions	55.86	(28.97)	61.33	(25.19)	54.11	(30.29)
Drought tolerance	82.31	(19.34)	86.44	(19.53)	81.18	(19.44)
Summer performance	70.83	(25.81)	81.78	(25.47)	67.65	(25.43)
Heat stress tolerance	73.76	(25.67)	81.44	(22.98)	71.59	(26.30)
Wear and traffic tolerance	78.38	(19.91)	80.67	(18.52)	77.71	(20.54)
Shade tolerance	67.48	(25.45)	58.20	(22.73)	70.38	(25.89)
Low mowing height tolerance	53.67	(25.96)	56.00	(32.31)	53.04	(24.70)
Low fertilizer requirements	61.18	(26.82)	65.50	(23.74)	59.64	(28.08)
Growth characteristics						
Aggressiveness	61.21	(27.11)	70.75	(33.10)	58.67	(25.33)
Nitrogen use efficiency	64.85	(24.01)	67.57	(29.40)	64.15	(23.02)
Natural tolerance to glyphosate	38.03	(32.13)	45.67	(41.27)	36.20	(30.29)
Quick germination	72.95	(17.57)	77.56	(20.23)	71.57	(16.83)
Germination reliability	75.41	(23.75)	58.17	(36.40)	79.11	(19.07)
Rapid tillering	68.33	(22.19)	77.88	(18.50)	65.61	(22.69)
Slower vertical growth rate	49.33	(24.61)	61.67	(34.16)	46.59	(21.87)
Seed yield	74.14	(26.98)	89.00	(19.12)	68.42	(27.66)

[z]The mean likelihood level of selecting each trait.

The summary statistics of the selection likelihood for each trait cluster are listed in Table 3. The overall likelihood of selecting abiotic stress resistance traits (such as salt tolerance, drought tolerance, summer performance, etc.) were the highest among all trait clusters, followed by growth characteristics (such as aggressiveness, germination reliability, seed yield, etc.), appearance characteristics (such as color, leaf texture, and turf density), and disease and pest resistance characteristics (such as disease resistance, insect resistance, allelopathy, and endophyte infection). Selection likelihood of trait clusters differed between breeders and distributors (Table 3). Breeders ranked the growth characteristics the highest, followed by abiotic stress resistance, appearance, and then disease and pest resistance, whereas distributors were most likely to select the abiotic stress resistance trait cluster, followed by growth characteristics, then disease and pest resistance, and they were least likely to select the appearance traits. We also conducted pairwise *t* tests and found that the differences in the selection likelihood between any two trait clusters were statistically significant (Table 4).

Selection likelihood for individual traits within each trait cluster is presented in Table 5. The likelihood of selecting appearance traits such as turf density, finer leaf texture, and dark color was high for all respondents. Specifically, breeders were more likely to select finer leaf texture and higher turf density compared with distributors. In terms of disease and pest resistance traits, breeders ranked endophyte infection, crown and stem rust resistance, and leaf spot resistance the highest, followed by resistance to brown patch summer patch and snow mold. Distributors, on the contrary, were least likely to select endophyte infection and most likely to select disease and pest resistance traits such as resistance to dollar spot and brown patch, followed by resistance to several diseases (leaf spot, summer patch, crown and stem rust, and snow mold), insect resistance, and allelopathy. Except for the shade tolerance, breeders were more likely to select the abiotic stress resistance traits than were distributors. Breeders also had the highest likelihood of selection for drought tolerance, followed by summer performance, heat stress tolerance, wear and traffic tolerance, lower fertilizer requirements, salt tolerance, shade tolerance, and low mowing height tolerance. As for growth characteristics, breeders gave higher ratings for most traits compared with distributors: they had the highest likelihood of selecting for traits such as seed yield, rapid tillering, and quick germination, followed by aggressiveness, nitrogen use efficiency, and slower vertical growth rate. Both breeders and distributors were least likely to select glyphosate tolerance trait. Nevertheless, distributors ranked germination reliability the highest, but breeders ranked it the lowest within the growth characteristic trait cluster.

Likelihood of selecting turfgrass trait. Estimation results of the Tobit model are presented in Table 6. The dependent variable was the reported likelihood of selecting each trait. The independent variables included the dummy variable of each trait cluster: disease and pest resistance, abiotic stress resistance, and growth characteristics. Each cluster dummy variable indicated that the observed traits were grouped into the corresponding cluster if it equaled one. To distinguish the differences in trait selection likelihoods between breeders and distributors, a dummy variable for breeders was included in the regression. In addition, some interaction terms were also included for the dummy variables for trait clusters and breeder to test if there are significant differences in the selection likelihood for the trait cluster between breeders and distributors when all the other program characteristics were controlled. The program background characteristics contained the program size, years of working experience, education level, and gender. Dummy variables for target regions were also included in the regression. The base group for this Tobit regression was a distributor targeting the Midwest region and the base trait cluster was appearance. In general, the positive and significant coefficient for the breeder dummy suggested that the breeders on average were more likely to select each trait cluster compared with distributors. The abiotic resistance and growth characteristics clusters were more likely to be selected compared with appearance trait cluster. The negative and significant coefficient for the *Breeder × Abiotic resistance* interaction indicated that compared with appearance traits, the likelihood of selecting abiotic stress resistance trait was smaller for breeders than for distributors. In addition, being male, having more education, or having a larger program increased the likelihood of selecting for all studied trait clusters. Compared with those who targeted the Midwest region, the selection likelihoods for those who were targeting Canadian regions were higher.

To investigate how various factors affect breeders and distributors selecting each trait cluster, we ran a Tobit model for each trait cluster. The results of the Tobit regressions are shown in Table 7. The dependent variables in these regressions were the reported

Table 6. Estimation results for Tobit model: the likelihood of selecting turfgrass traits by U.S. turfgrass breeders and distributors.[z]

Variables	Coefficient[y]
Intercept	32.49***
	(5.73)
Trait cluster variables	
Disease and pest resistance[x]	–0.11
	(0.03)
Abiotic stress resistance[x]	14.89***
	(4.32)
Growth characteristics[x]	8.08**
	(2.31)
Breeder[w] × Disease and pest resistance[x]	–9.77
	(1.27)
Breeder[w] × Abiotic stress resistance[x]	–15.29**
	(2.03)
Breeder[w] × Growth characteristics[x]	–10.18
	(1.33)
Characteristics of the program	
Breeder[w]	16.98**
	(2.61)
Program size	0.10***
	(3.99)
Work years	–0.06
	(0.61)
Education	3.01***
	(3.88)
Male	6.40*
	(1.88)
West	0.42
	(0.14)
Northeast	–0.30
	(0.10)
South	–0.23
	(0.06)
Canada	12.38***
	(3.68)

[z]The dependent variable for this Tobit model was the selection likelihood of turfgrass trait range from 0 to 100. The base group for this Tobit regression was a female distributor targeting the Midwest region and the base trait cluster was appearance.

[y]Absolute *t* statistics in parentheses; *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

[x]The trait cluster variables were dummy variables which equaled 1 if an observed trait was in the corresponding trait cluster.

[w]Breeder was a dummy variable which equaled 1 if the respondent was a breeder and 0 otherwise.

likelihoods of selecting the corresponding trait clusters. The independent variables were the ratings for the interested parties, background characteristics of the program, and binary variables for target regions. The base group for this Tobit regression was a female distributor targeting the Midwest region.

Appearance. Being a breeder or a male significantly increased the selection likelihood for the appearance cluster. Marketing companies had a significant positive impact on the selection likelihood of this trait cluster for distributors. For breeders, consumers and marketing companies positively impacted the selection likelihood of appearance cluster, whereas producers/growers and wholesalers had negative impacts.

Disease and pest resistance. Similar to the results for appearance traits cluster, the selection likelihood of disease and pest resistance cluster was positively influenced by the ratings of importance of marketing companies. Breeders, in comparison with distributors, were generally more likely to select the disease and pest resistance cluster. From the perspective of a turfgrass breeder, consumers and marketing companies had positive effects, whereas producers/growers and wholesalers had negative impact on the selection likelihood of disease and pest resistance cluster. This finding is consistent with Gallardo et al. (2012) that the consumers and marketers had significant positive effect on the selection likelihood of biotic (disease and pest) stress resistance. Moreover, compared with the base group, being male, having a larger program or more years of experience had significant and positive effects on the selection likelihood of disease and pest resistance traits. Compared with respondents targeting the Midwest region, respondents working in the South were more likely to select this trait cluster, whereas those who work in the Northeast were less likely.

Table 7. Estimation results for Tobit models: U.S. turfgrass breeder and distributor selection likelihood for each trait cluster.[z]

Variables	Appearance[y]	Disease and pest resistance[y]	Abiotic stress resistance[y]	Growth characteristics[y]
Intercept	–110.30*	–92.50**	–107.00**	–48.60
	(1.70)	(2.01)	(2.53)	(1.22)
Interested parties				
Consumers[x]	3.99	4.23	7.78***	7.49***
	(0.95)	(1.46)	(3.01)	(2.73)
Producers/growers[x]	–1.48	–1.64	–0.33	1.87
	(0.45)	(0.69)	(0.15)	(0.86)
Wholesalers[x]	1.03	–2.55	–0.60	–3.27
	(0.25)	(0.88)	(0.22)	(1.22)
Marketing companies[x]	8.89***	10.60***	7.33***	4.88***
	(2.99)	(5.28)	(3.83)	(2.64)
Sales staff needs[x]	–0.16	0.56	0.49	–1.47
	(0.06)	(0.27)	(0.28)	(0.85)
Breeder[w] × Consumers[x]	34.30**	48.20***	24.90***	40.50***
	(2.50)	(4.62)	(2.94)	(4.17)
Breeder[w] × Producers/growers[x]	–42.90**	–58.80***	–24.50**	–49.20***
	(2.43)	(4.44)	(2.17)	(3.91)
Breeder[w] × Wholesalers[x]	–95.90**	–104.90***	–54.90**	–95.70***
	(2.50)	(3.65)	(2.25)	(3.53)
Breeder[w] × Marketing companies[x]	82.10*	96.00***	42.70	94.50***
	(1.92)	(3.01)	(1.56)	(3.12)
Characteristics of the program				
Breeder[w]	224.60**	210.50***	113.40*	158.50**
	(2.22)	(3.03)	(1.78)	(2.38)
Program size	0.09	0.13*	0.20***	0.21***
	(0.87)	(1.70)	(3.09)	(3.07)
Work years	0.67	0.96**	0.67	0.41
	(0.95)	(2.02)	(1.48)	(0.97)
Education	2.55	–0.28	2.93	–2.04
	(0.48)	(0.08)	(0.86)	(0.61)
Male	73.60***	64.90***	49.20***	35.40**
	(2.77)	(3.29)	(2.83)	(1.98)
West	–0.81	11.40	–0.64	2.04
	(0.06)	(1.21)	(0.08)	(0.24)
Northeast	–16.40	–13.00*	–20.10***	–2.71
	(1.57)	(1.86)	(2.97)	(0.42)
South	15.30	14.50*	10.60	6.41
	(1.23)	(1.66)	(1.34)	(0.80)
Canada	15.80	10.80	18.60	1.33
	(0.64)	(0.62)	(1.19)	(0.08)

[z]The dependent variable for these Tobit models were the average selection likelihood of four turfgrass trait clusters, ranging from 0 to 100. The base group for this Tobit regression was a female distributor targeting the Midwest region.

[y]Tobit regression results for each trait cluster presented in corresponding column. Absolute *t* statistics in parentheses; *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

[x]The importance level of each interested party was rated by respondents ranging from 0 to 10.

[w]Breeder was a dummy variable which equaled 1 if the respondent was a breeder and 0 otherwise.

Abiotic stress resistance. Distributors perceived consumers and marketing companies' needs positively affecting the selection likelihood of abiotic stress resistance traits. Although breeders were more likely to select the abiotic stress resistance traits compared with distributors, this difference was only significant at 10% level. For breeders, consumers' needs were considered to positively affect the selection likelihood of the abiotic stress resistance traits, whereas the producers/growers' and wholesalers' needs had negative effects. Both distributors and breeders regarded consumers as one of the most influential parties when selecting this trait. These results are consistent with previous research findings that consumers are willing to pay premiums for produces less exposed to pesticides (Govindasamy and Italia, 1998). This also reflects the market trend that consumers prefer turfgrass cultivars that are more resistant to abiotic stresses. For example, Yue et al., (2012) found that consumers are interested in the low-input (low fertilizer, low pesticides, and less maintenance required) turfgrass species; they also suggested that there exists a large potential market for this consumer group. Compared with the base group, male respondents and respondents with larger program size were more likely to select the abiotic resistance traits, whereas those who target the Northeast regions were less likely to select this trait cluster.

Growth characteristics. For distributors, consumers' and marketing companies' needs positively and significantly affected the likelihood of selection for growth characteristics. The impact of producers/growers' needs on growth characteristics was positive but not statistically significant. For breeders, consumers' needs were considered to positively affect the selection likelihood of the growth characteristics, whereas the producers/growers' and wholesalers' needs had negative effects. Being male and having larger program size had positive effects on the selection likelihood of the growth characteristics trait cluster.

Conclusions

With thirty turfgrass traits to consider, we aggregated individual turfgrass traits into clusters based on the traits' similarities. Overall, breeders had higher likelihoods in the selection of the studied turfgrass traits compared with distributors. The most important trait clusters for both breeders and distributors were abiotic stress resistance and growth characteristics. Breeders were more likely than distributors to select appearance trait cluster when setting trait priorities.

Program characteristics such as program size, education level, and being a male respondent had positive effects on the reported likelihood of selecting turfgrass traits, and these effects varied for different trait clusters. In terms of the important parties, consumers and marketing companies positively affected the selection likelihood of abiotic resistance and growth characteristics for both breeders and distributors. Marketing companies' needs were positively related to the likelihood of selecting appearance, disease and pest resistance traits. In general, we find that consumer-driven forces (i.e., consumers and marketing companies) had positive impacts on the breeders' likelihood of selecting the studied traits. Producers/growers' needs had some positive effect on the likelihood of selection for growth characteristics, but this effect was not statistically significant.

Our investigation on the important factors affecting breeders and distributors' priority setting and decision-making process on trait selection can provide important implications and insights about the breeding/distributing practices for the turfgrass industry. Although we found different priorities for breeders and distributors when selecting turfgrass trait priorities, the impact of consumers and marketing companies' needs were mostly consistent. This finding indicated that the trait prioritization in turfgrass industry is market oriented. Turfgrass breeders, growers, distributors, and other parties in the supply chain could benefit from market studies on consumers who purchase turfgrass seeds and grasses.

Our previous research on turfgrass market has found that consumers desire low-input turfgrass traits (Yue et al., 2016), yet they have difficulty finding turfgrasses with these traits at retailers. Combined with our breeder/distributor results, this shows a disconnect between distributors and consumers which points to an opportunity for distributors to increase the sale of improved stress-tolerant turfgrass cultivars by shifting trait selection priorities. To align with consumers' needs, future breeding efforts could focus on the development of abiotic traits such as wear and traffic tolerance, drought tolerance, low mowing height tolerance, and low fertilizer requirements. Furthermore, our results will allow stakeholder groups and funding agencies to better understand the needs of the entire supply chain and help breeding programs coordinate with supply chain demand more efficiently.

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