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Full Length Research Paper

Evaluation of resistance in wheat germplasm to the aphids, *Sitobion avenae* based on Technique for Order Preference by Similarity to Ideal Solution) TOPSIS and cluster methods

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***Sitobion avenae* is the dominant and destructive pest in wheat production regions in China. Therefore, breeders developed new and high resistant varieties to ensure stable yields. In this paper, thirteen comprehensive agronomic characteristics of twenty-two wheat germplasm resources were investigated, and the data for the resources collected in the latest two years were treated with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS method) and cluster analysis. The priority order of alternatives ranks obtained from the TOPSIS method and aphid index analysis is the same. The order of alternatives ranks is as follows: Yumai70>Amigo>186Tm>Xiaoyan22>PI>Donghan1>98-10-35>…>Datang991>Qianjinzao. It was also found that the examined 22 wheat germplasm resources could be agglomerated into four clusters. Five good germplasm, namely 186Tm, Yumai70, AMIGO, Xiaoyan22, 98-10-35, could be used directly or as parents for breeding wheat varieties for resistance to *S. avenae*. Furthermore, the results showed TOPSIS analysis and cluster analysis are highly consistent with each other. But TOPSIS method is the best comprehensive method for the evaluation of resistance in wheat breeding to the aphids.**

Key words: Wheat (*Triticum aestivum*), germplasm resources, agronomic characteristic, *Sitobion avenae*, technique for order preference by similarity to ideal solution method, cluster analysis.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important food crops in the world (Duveiller et al., 2007; Ortiz et al., 2008). In China, wheat is the third-largest food crop, after rice and maize respectively, and winter wheat covers 23.4 million ha in 2007 (Wang et al., 2009). The grain aphid, *S. avenae* , which appears as small, soft-bodied, sucking insects (Ciepiela, 1989; Hu et al., 2009) is among the most dominant pests of wheat in China. It has been recorded to cover an area of about 16.7 million hm^2 of wheat production areas in Yellow Huai and the Northern China Plain, the Southwest, Northwest and the Middle Yangtze River (Zhang et al., 2009). As a result, *S. avenae* can cause as much as 15 to 60% of severe cases reduction in yield and quality of food crops. The use of resistant varieties is one of the most effective means and preferred management tactic of controlling this pest (Du Toit, 1987, 1988) because it is less expensive and not detrimental to the environment or natural enemies of the resistant varieties (Mornhinweg and Porter, 2002). However, developing resistant varieties is time-consuming, specifically in wheat, which can take at least 10 years. Resistant lines must be laboratory and field tested and superior selections must be screened (Sleper and Poehlman, 2006). At present, the method of aphid index is a common way of identifying the resistance to naturally infested field. TOPSIS (technique for order preference by similarity to ideal solution) was firstly proposed by Hwang and Yoon in 1981 (Hwang and Yoon, 1981). This kind of analysis method can be adapted to assess multi-indices of the quality of Chinese herbal

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Table 1. Scale of Identification for wheat resistance to *S. avenae* (F.)

Resistance scale	Resistance	Aphid indexes
0	Immunity	0.00
1	Highly resistant	0.01-0.30
2	Moderately resistant	0.31-0.60
3	Lowly resistant	0.61-090
4	Lowly susceptible	0.91-1.20
5	Moderately susceptible	1.21-1.50
6	Highly susceptible	>1.50

medicines (Peng et al., 2009). It has been concluded with TOPSIS analysis that under Pi deficient and sufficient conditions, rapeseed variety, W17 ranks first and W39 ranks last. For the other varieties, TOPSIS ranking had a certain degree of coherence with field observations. This indicates that TOPSIS can improve material identification varieties (Lu et al., 2009).

Clustering analysis is a multi-trait analysis method, which has been proved to be a more feasible evaluation method in the study of the differences and classification of crop germplasm resources (Zhang et al. 2001). Applying the agronomic traits of wheat germplasm to screen the resistance is a more objective way, which provides the basis for selecting the hybrid wheat breeding parents (Zhang et al., 2001). However, the lack of high resistant germplasm resources with advanced comprehensive agronomic characteristics has affected the efficiency of breeding to *S. avenae*. The current study reports the results of simultaneous screening and evaluation of wheat germplasm lines for resistance at problem locations in China. The work also lists promising genotypes with both advanced agronomic characteristics and resistance which may be used for breeding programs.

Moreover, our results present a detailed example of the wheat-aphid interaction system and suggest possible exploration approaches for the wheat germplasm by *S. avenae*.

MATERIALS AND METHODS

Materials and experimental sites

Twenty-two wheat germplasms, which were collected mainly from Shaanxi, Henan, Hebei, Jiangsu, Sichuan, Guizhou provinces of China, Germany, and the United States, were screened under field conditions at two different agro-ecological locations. All the materials were also planted at the Experimental Farm of Northwest A&F University for measuring their agronomic characteristics.

Agronomic characteristics test

The field trials were established over two successive seasons (2008/2009 and 2009/2010). Each wheat germplasm lines was sown in two row plots of 200 cm in length, 100 cm between rows, 60 grains for each row, and two replications with a completely randomized design. The estimated agronomic traits were plant height (cm), spike length (cm), number of grains/spike, grain weight/plant (g), uniformity, and neck length (cm).

Identification for resistance to aphid

Resistance Identification was under natural infection. On each germplasm the number of aphids was counted on the damage heaviest 10 stems to investigate the total number of *S. avenae* (four replicates for each germplasm) from jointing stage to the grain-filling stage. Infested plants were investigated every seven days. The aphids index (average of number of a certain germplasm of aphids per plant/average of number all germplasm of aphids per plant) was calculated. The aphids index was indicated in 7 scales as shown in Table 1 (Painter et al., 1982).

Statistical analyses

Cluster analysis was used to arrange a set of variables into clusters. The aim was to establish a set of clusters so that cases within a cluster were more similar to each other than within other clusters. Each cluster of collected data thus described the class to which its members belonged. The cluster analysis was performed using a measure of similarity levels and Euclidean distance (Everitt et al., 2001; Eisen et al., 1998). The statistical population for cluster analysis was 22 germplasms. For each germplasm the most representative classification standard of wheat aphid resistance level was chosen and assigned accordingly. The cluster analysis using proc cluster of SAS (SAS Institute, 2001) was used to merge resistance of germplasms with similar characteristics in neck length, plant height, uniformity, spike length, grain number, and spike weight per plant.

The 13 main traits of 22 germplasm were compared to quantify the criteria value by TOPSIS method, which is one of the best described mathematical approach for practical using. Lin et al. (2008) proposed the model of TOPSIS method (Lin et al., 2008: Turskis et al., 2010) with attributes values determined at intervals. Multi -objective decision was used for “ideal solution” and “negative-ideal solution” to sort and compare the differences between the various indicators in accordance with the sort of Ci size. The greatest one was the most excellent germplasm. The formula was as follows:

$$R_{ij} = W_j \times Z_{ij}; \quad (1)$$

$$X^{+} = \left(X_1^{+}, X_2^{+},, X_n^{+}\right), X^{+}_j = \max_i \left(R_{ij}\right) \quad (2)$$

$$X^{-} = \left(X_1^{-}, X_2^{-}, X_n^{-}\right), X^{-}_j = \min_i \left(R_{ij}\right)' \quad (3)$$

Table 2. Aphid index and resistance scale of the wheat germplasms in Shannxi for the harvest in 2008- 2010.

Wheat genotypes	Aphid indexes	Resistance scale	Wheat genotypes	aphid indexes	Resistance scale
ZB11	0.9729±0.3501abcde	4	Qianjinzao	1.843±0.2098ab	6
Xiaoyan22	0.4262±0.0854bcde	2	963	1.8388±0.4489ab	6
98-10-35	0.485±0.0922bcde	2	Xun99-7	0.6853±0.134bcde	3
AMIGO	0.3477±0.0755cde	2	Yumai49	1.7007±0.3051abcd	6
Zhengmai9694-1	0.8786±0.369abcde	3	Shixin733	1.5762±0.6129abcde	6
Donghan1	0.6052±0.1234bcde	3	806	1.6027±0.6142abcde	6
Zhi95240	0.8091±0.32abcde	3	04-F6-816	2.2035±0.3831a	6
ZB07	1.3457±0.5383abcde	5	Datang991	1.7194±0.9197abcd	6
Yumai70	0.2168±0.0644e	1	929	1.7604±0.2153abc	6
PI	0.5455±0.1583bcde	2	Zhou91177	2.2256±0.9124a	6
ZhongCII2	1.577±0.4213abcde	6	186Tm	0.2859±0.0803de	1

Values in columns followed by the same letter are not significantly different, Different letters are significantly different (P<0.05).

$$D_i^{+} = \sqrt{\sum_{j=1}^{n} (R_{ij} - X_j^{+})},$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{n} (R_{ij} - X_j^{-})},$$

$$C_i = D_i^{-} / \left(D_i^{-} + D_i^{+}\right). \quad (4)$$

m – Germplasm; n – trait; (i = 1, 2, 3, , m; j = 1, 2, 3, n);
R_{ij} - Weighted normalized matrix;
X^+ - Ideal solution; X negative-ideal solution;
D_{i+} - The distance between various lines (types) and the ideal solution;
D_{i-} - The distance between various lines (types) and the negative ideal solution;
C_i - The relative proximity of lines (varieties) to ideal solution.

Appropriate statistical analysis was conducted using SAS (SAS Institute, 2001) and SPSS 16.0 (SPSS Inc., 2007) packages.

RESULTS

Statistical analyses

Table 2 shows aphid indexes and resistance scale, mean and standard error for all estimated variables of wheat. Significant differences were found in identification results by the field of natural sense of aphid, The results indicated that the resistances of different wheat resources to aphid were not in immunity type. The differences were only observed in highly resistance, moderately resistance, lowly resistance, lowly susceptible, moderately susceptible and highly susceptible varieties. Among the 22 germplasm resources shown in Table 1, two copies of the materials, namely, Yumai 70 and 186Tm, present high resistance; the germplasm resources with moderate resistance were 4 copies, which were Amigo, 98-10-35, Xiaoyan 22, and PI, respectively; low resistance were 4 copies, which were Zhengmai 9694-1, Donghan 1, Xun 99-7, Zhi 95240; lowly susceptible variety was 1 copy, which was ZB011; moderately susceptible variety was 1 copy, which was ZB07; highly susceptible variety were 10 copies, which were qianjinzao, Yumai 49, Datang 991 and Zhou 91177, Shixin733, etc.

The results revealed that all germplasm resources included in the study have significant.

TOPSIS analyses

Table 3 shows the means of main characters of 22 germplasms at all levels. Ranking of alternatives resistance was performed by applying TOPSIS method. The initial decision-making matrix was obtained by using the means of main characters of 22 germplasms in Table 3.

In Table 3, 22 wheat genotypes and 13 main characters are given, among which the 13 main characters were undertaken a comprehensive analysis using TOPSIS method. The means of main characters were calculated by changing in the normalization matrix of comprehensive evaluation (Table 4), which were the ideal solution and negative ideal solution to all traits that in optimal value of vector and the worst value of vector.

The optimal value of vector (the ideal solution) is:
X^+ = (0.0816, 0.0256, 0.0159, 0.0292, 0.0137, 0.019, 0.0338, 0.0157, 0.0244, 0.0135, 0.0262, 0.0176 and 0.035).

The worst value of vector (negative ideal solution) is:

Table 3. Normalized decision-making matrix.

Genotypes	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
ZB011	0.0182	0.0064	0.0098	0.0168	0.0118	0.0122	0.0168	0.0122	0.0202	0.0122	0.0218	0.0088	0.0154
Xiaoyan22	0.0415	0.0128	0.0109	0.0186	0.0094	0.0078	0.0258	0.0073	0.0214	0.0111	0.0208	0.0096	0.0263
98-10-35	0.0365	0.0128	0.0122	0.0144	0.0128	0.019	0.015	0.0092	0.021	0.0122	0.0174	0.0176	0.0123
Amigo	0.0509	0.0128	0.0159	0.0234	0.013	0.0148	0.0338	0.0061	0.0202	0.0092	0.0173	0.008	0.0278
Zhengmai9694-1	0.0201	0.0085	0.01	0.0228	0.0137	0.0113	0.0264	0.0092	0.02	0.0102	0.0235	0.0088	0.0326
Donghan1	0.0292	0.0085	0.0109	0.021	0.0119	0.0111	0.0264	0.0092	0.0234	0.0122	0.0262	0.0096	0.035
Zhi95240	0.0219	0.0085	0.0108	0.0217	0.0115	0.0108	0.0216	0.01	0.0214	0.0087	0.0237	0.0059	0.019
ZB07	0.0131	0.0051	0.0111	0.0199	0.0113	0.0081	0.0222	0.011	0.021	0.0135	0.0234	0.0088	0.0267

Table 3. Contd.

Yumai70	0.0816	0.0256	0.01	0.0208	0.0084	0.0056	0.0198	0.0122	0.0232	0.0122	0.0229	0.0176	0.0324
PI	0.0492	0.0128	0.0093	0.019	0.0095	0.0101	0.0132	0.0138	0.0192	0.0122	0.0217	0.0096	0.0118
ZhongCII2	0.0112	0.0043	0.0105	0.0292	0.0104	0.0112	0.0228	0.0092	0.0224	0.0087	0.02	0.0075	0.0185
Qianjinzao	0.0096	0.0043	0.0084	0.0181	0.0094	0.0098	0.0132	0.01	0.0188	0.0122	0.0169	0.0096	0.0107
963	0.0112	0.0043	0.0104	0.0203	0.0111	0.0064	0.0228	0.0085	0.0236	0.0081	0.021	0.0106	0.0127
Xun99-7	0.0258	0.0085	0.0107	0.0221	0.0096	0.0095	0.0204	0.01	0.0244	0.0135	0.0242	0.0088	0.0227
Yumai49	0.0104	0.0043	0.0095	0.023	0.0098	0.01	0.0174	0.011	0.0208	0.0072	0.0209	0.0151	0.0169
Shixin733	0.0112	0.0043	0.0111	0.0208	0.0099	0.0091	0.021	0.0157	0.0196	0.0087	0.024	0.0117	0.0283
806	0.011	0.0043	0.0098	0.0292	0.0114	0.012	0.0318	0.0079	0.0218	0.0111	0.0182	0.0066	0.0165
04-F6-816	0.008	0.0043	0.0098	0.0257	0.0088	0.0064	0.0174	0.0138	0.023	0.0072	0.025	0.0088	0.0224
Datang991	0.0103	0.0043	0.0102	0.0234	0.0088	0.0069	0.0138	0.0085	0.0224	0.0094	0.0222	0.007	0.0087
929	0.0101	0.0043	0.0108	0.0181	0.01	0.0111	0.0186	0.0122	0.0212	0.0094	0.0215	0.0096	0.0173
Zhou91177	0.0079	0.0043	0.0086	0.0208	0.0094	0.0095	0.0222	0.01	0.0228	0.0094	0.018	0.0117	0.0139
186Tm	0.0619	0.0256	0.0117	0.0115	0.0107	0.0127	0.0084	0.0122	0.0156	0.0122	0.0134	0.0132	0.0053
The optimal value of vector	0.0816	0.0256	0.0159	0.0292	0.0137	0.019	0.0338	0.0157	0.0244	0.0135	0.0262	0.0176	0.035
The worst value of vector	0.0079	0.0043	0.0084	0.0115	0.0084	0.0056	0.0084	0.0061	0.0156	0.0072	0.0134	0.0059	0.0053

X^{-} = (0.079, 0.0043, 0.0084, 0.0115, 0.0084, 0.0056, 0.0084, 0.0061, 0.0156, 0.0072, 0.0134, 0.059 and 0.0053).

According to vectors of the optimal value and the worst value, calculation of the distance and its relative value close to the optimal value of the degree of sorting in the size of Ci, to the index value and the optimal value and the worst value (Table 5) is carried out. Ci, value was between 0 and 1, the more the value was close to 1, the larger the value Ci was, the more excellent strain was. Otherwise, the results would be on the contrary. In Table 5, the order of alternatives ranks is the same according to the TOPSIS methods and aphid index analysis. The priority order is:

Yumai 70 > Amigo >186 Tm > Xiaoyan 22 > PI> Donghan 1 > 98-10-35 >…> Datang 991 > Qianjinzao. The first resistance of alternative germplasms resources to aphid must be Yumai 70, which showed the best performance.

Cluster analysis

In order to clearly verify the germplasm resistantance to aphid, the 13 main traits of 22 germplasms were investigated by cluster analysis and the results are shown in Table 3. Cluster analysis with wheat main traits was used and a dendrogram (Figure 1) can be obtained by average linkage (between groups).

Figure 1 shows resistance scales of wheat germplasms by using the hierarchical cluster analysis. The examined 22 wheat germplasm resources could be agglomerated into four clusters if the threshold T = 6.00 by Euclidean distance was used. Cluster 1 included Amigo, while cluster 2 included 98-10-35,186 Tm. Cluster 3 included Yumai 70, Zhi 95240, Zhengmai 9694-1, Xun 99-7, ZB07, Xiaoyan 22, Datang 991, and others. Cluster 4 included qianjinzao, Yumai 49, PI ZB011 and others.

Our data indicated the tendency of resistance for each grouped wheat germplasm resources in one clusters relate closely to each other. Therefore, the current study results demonstrated that main characters were wheat germplasm resources, which related most closely to resistance.

DISCUSSION

The methods of identification of wheat germplasm for resistance to *S. avenae*

Large numbers of works concerning identification

Table 4. The computed results of TOPSIS.

Genotypes	D^+	D^-	C_i	Rank	Resistance scales
ZB011	0.0737	0.023	0.238	16	4
Xiaoyan22	0.0487	0.0461	0.486	4	2
98-10-35	0.0586	0.0377	0.3911	7	2
Amigo	0.0389	0.0584	0.6003	2	2
Zhengmai9694-1	0.0665	0.0397	0.3735	8	3
Donghan1	0.0579	0.0457	0.4412	6	3
Zhi95240	0.068	0.0296	0.3034	10	3
ZB07	0.0753	0.0311	0.2926	13	5
Yumai70	0.0233	0.0847	0.7844	1	1
PI	0.0503	0.0458	0.4766	5	2
ZhongCII2	0.0782	0.0291	0.2716	14	6
Qianjinzao	0.0846	0.014	0.1416	22	6
963	0.0804	0.0226	0.2197	18	6
Xun99-7	0.0635	0.0343	0.3505	9	3
Yumai49	0.0801	0.0238	0.2295	17	6
Shixin733	0.0769	0.0326	0.2979	12	6
806	0.0783	0.0336	0.3001	11	6
04-F6-816	0.0816	0.0289	0.2614	15	6
Datang991	0.0841	0.0182	0.1777	21	6
929	0.0804	0.0221	0.2156	19	6
Zhou91177	0.0827	0.0222	0.2118	20	6
186Tm	0.0507	0.0595	0.5400	3	1

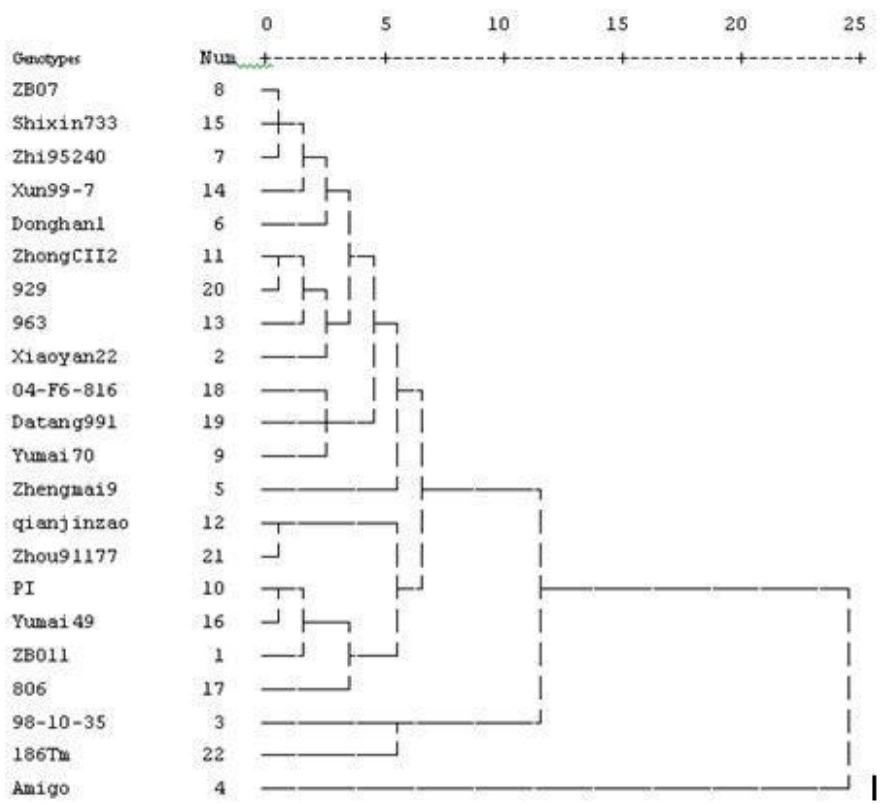

Figure 1. Different resistant level of gemplasm resources using the hierararchical cluster analysis.

for resistance to *S. avenae* have been reported, such as the index of infestation aphid, fuzzy recognition, Painter's the 7th scales for resistance, electrical penetration graph (EPG), glasshouse Identification of seedling technique, et al. At present, the index of infestation aphid is a common way of identifying the resistance to naturally infest aphid in the field in China. Using this method as an indirect identification technique showed that the accessions of PI and 98- 10-35 have the different identification results from 2003 to 2009 (Hu et al., 2004; Li et al., 2007). The 98-10-35 showed moderate resistance in our research. However, the result of PI in our research was different from that of the previous researches.

It demonstrates that environment conditions have significant effects on aphid occurred. Meanwhile, using the method of the index of infestation aphid still revealed defects in identification of the resistance to *S. avenae.*

Application on high resistance wheat germplasm resources to aphid

Since the 1980s, a lot of works was conducted to screen and identify wheat germplasm for resistance to *S. avenae* by Chinese researchers (Liu et al.,2006; Shi., 2008), however, China's current wheat germplasm for resistance to *S. avenae* still remains relatively rare. Especially for the current main cultivars, there are only very few varieties. The materials of our research have come from the ordinary wheat germplasm, which not only have high antibiosis to *S. avenae* but also have higher application value in wheats' breeding of insect resistance. Meanwhile, excavating wheat- related plants germplasm for resistance to *S. avenae* and introducing foreign resistance germplasm resources are supposed to be another important aspect.

Evaluation effect of wheat resistance to aphid by TOPSIS method

Applying the TOPSIS and cluster analysis methods objectively evaluates the quality of the resistance of some strains. The quality of comprehensive traits was dominated by not only main factors but also seed weight per plant, uniformity, resistance level, and so on. The 13 traits were adapted to comprehensively evaluate the ranking of resistance. Meanwhile, the result was proved to be reliable. TOPSIS rank and cluster results had a certain degree of coherence with the ranking of index of infestation aphid. It was also proved that applying the agronomic characters to screen the resistance of germplasm resources was feasible. For these different resistance levels of wheat germplasm, previous reports haven't mentioned that applying 13 main traits to TOPSIS analysis in order to evaluate the resistance levels of wheat germplasm.

The shortcomings of TOPSIS analysis were that the weight was not set properly, and the different definitions of the distance were not adopted. For example, the result might be different in the case of applying Euclidean or deviation distance to TOPSIS analysis. In other words, the result of TOPSIS analysis may affect setting properly weight and the definition of the distance. The further studies need to be conducted in order to know how to obtain better balance.

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