Asian Agricultural Research 2018, 10(11): 92 –94 DOI: 10.19601/j.cnki.issn1943 –9903.2018.11.019

Comprehensive Evaluation of New Fresh Edible Sweet-glutinous Maize Varieties Based on Entropy Weight Method

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Abstract In this study, the entropy weight method was used to comprehensively evaluate the eight sweet-glutinous maize varieties in the regional trials in Shanxi Province in 2016. The results showed that the order of the performance of comprehensive traits of the tested varieties was Heitiannuo 631, Heitiannuo No. 2, Cainuo No. 5, Xinnuo 8601, FYN 1601, Xinnuo 8608, Jindannuo 41, Caitiannuo 1958 (from good to poor). Among them, Heitiannuo 631, Heitiannuo No. 2 and Cainuo No. 5 are excellent varieties, and the rest are good varieties.

Key words Entropy weight method, Fresh edible maize, Comprehensive evaluation

1 Introduction

Fresh edible sweet-glutinous maize, as a high-efficiency crop for both fruit and vegetable, is rich in nutrients, sweet, glutinous, fragrant, and fresh. It has good palatability and unique flavor and is loved by people[1]. Due to wide consumer base and high economic benefits, its planting area is becoming wider and wider. The constantly updated varieties provide the basic guarantee for the healthy and sustainable development of the sweet-glutinous maize industry. Regional trials of sweet-glutinous maize varieties are an important process for comprehensively identifying, evaluating and screening varieties. How to scientifically and reasonably evaluate the varieties tested is of great significance for the validation, promotion and development of new varieties. There are many comprehensive evaluation and analysis methods currently used for regional trials of new varieties. However, these multi-objective fuzzy comprehensive analysis methods have the limitation of artificial assignment of weight of traits, making evaluation results less scientific[2]. To this end, the entropy weight method was introduced to the comprehensive evaluation and screening of sweet-glutinous maize to overcome the limitation of artificial weighting of each target trait, thereby achieving a more scientific and effective comprehensive evaluation of varieties.

2 Principal and method of comprehensive evaluation of new fresh edible sweet-glutinous maize varieties by entropy weight method

There are n tested varieties and m observed traits to form an evaluation matrix.

$$X = (x_{ij})_{m \times n} (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m).$$

where x_{ij} represents the observation value of the j-th trait. The evaluation matrix is normalized to eliminate the incomparability of each index due to different dimensions and obtain a normalized matrix. The process is as follows.

If the trait j is a trait, the greater the better,

$$r_{ij} = x_{ij}/\max(x_{ij}) (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m) \quad (1)$$

If the trait j is a trait, the smaller the better,

$$r_{ij} = \min(x_{ij})/x_{ij} \quad (2)$$

If the trait j is a moderate trait,

$$r_{ij} = \begin{cases} 1 & x_{ij} \in (q_1, q_2) \\ x_{ij}/q_1 & x_{ij} < q_1 \\ q_2/x_{ij} & x_{ij} > q_2 \end{cases} \quad (3)$$

The trait weight vector is set as ω_i,

$$\omega_j = (\omega_1, \omega_2, \cdots, \omega_m), (j = 1, 2, \cdots, m) \quad (4)$$

where ω_j represents the importance of the index j in the index set, and $0 \leqslant \omega_i \leqslant 1$, $\Sigma\omega_j = 1$. The weight of each trait is calculated according to the information entropy theory to overcome the limitations caused by artificial assignment.

The comprehensive trait evaluation value of each variety is set as V_i,

$$V_i = \sum_{j=1}^{m} r_{ij}\omega_j (0 \leqslant V_i \leqslant 1) \quad (5)$$

The matrix $R = (r_{ij})_{n \times m}$ is normalized to obtain a matrix R′,

$$R' = (P_{ij})_{mn}, P_{ij} = r_{ij}/\sum_{i=1}^{n} r_{ij} (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m) \quad (6)$$

The entropy value E_j of the j-th evaluation index can be calculated according to the following formula,

$$E_j = -\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij}\ln P_{ij} \quad (7)$$

When $P_{ij} = 0$, $P_{ij} \ln P_{ij} = 0$.

$$\omega_i = (1 - E_j)/\sum_{k=1}^{m}(1 - E_k)$$

The determination of the weight vector has an important impact on the results of comprehensive evaluation. According to the principle of entropy weight information theory, the smaller the information entropy between the trait values of each evaluation object is, the greater the amount of information that can be provided is, and the greater the role played in the evaluation process is, and *vice versa*. Then, using the golden section principle, the value of $V_i(0-1)$ is divided into five ranges corresponding to five types of

Received: September 12, 2018 Accepted: November 2, 2018

Supported by Biological Breeding Project of Shanxi Academy of Agricultural Sciences (17yzgc057).

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comment ($0.854 \leqslant V_i \leqslant 1$, excellent; $0.618 \leqslant V_i < 0.854$, good; $0.528 \leqslant V_i < 0.618$, moderate; $0.382 \leqslant V_i < 0.528$, poor; $V_i < 0.382$, worse).

3 Evaluation and analysis of tested sweet-glutinous maize varieties in regional trials in Shanxi Province in 2016

3.1 Tested varieties and experimental design A total of eight sweet-glutinous maize varieties were tested in the regional trials of sweet-glutinous maize in Shanxi Province in 2016, Xinnuo 8601, Xinnuo 8608, Caitiannuo 1958, FYN 1601, Heitiannuo No. 2, Cainuo No. 5, Heitiannuo 631, and Jindannuo 41 (CK). The five pilots were the Institute of Sorghum of Shanxi Academy of Agricultural Sciences (Yuci), Institute of Variety Resources of Shanxi Academy of Agricultural Sciences (Taiyuan), Institute of Maize of Shanxi Academy of Agricultural Sciences (Xinzhou), Tunliu County Agricultural Crop Testing Center (Changzhi), and Shanxi Wenshui Sansen Agriculture and Animal Husbandry Cooperative (Fenyang). The randomized block design was adopted. Three replicates were arranged for each treatment. There were five rows in each plot. The area of each plot was 20 m^2. The three rows in the middle of each plot (10 m^2) were harvested to calculate the yield. The number of protection rows is not less than 4. The production test is designed by the adjacent (or contrast) method, without replicates. The area of each plot was 300 m^2. The planting density was 52 500 plants/ha. There were 10 – 15 rows in each plot, with more than four protection rows.

3.2 Results of regional trials The ten traits of the eight tested sweet-glutinous maize varieties such as plant height, ear position, ear length, ear diameter, yield, and quality score were evaluated (Table 1). For the traits of growth period and bald tip length, the smaller the better; for the traits of ear length, ear diameter, number of rows per ear, number of grains per row, yield, and quality score, the greater the better; and the traits of plant height and ear position are moderate traits. Generally, the plant height is 240 – 280 cm, and the ear position is 80 – 120 cm.

Table 1 Results of regional trials of fresh edible sweet-glutinous maize varieties in Shanxi Province in 2016

Variety	Growth period//d	Plant height//cm	Ear height//cm	Ear length//cm	Ear diameter//cm	Bald tip length//cm	Number of rows per ear	Number of grains per row	Yield kg/ha	Quality score	V_i
Xinnuo 8601	88	246	108	19.54	5.00	0.9	16	36	15 067.5	85	0.810 73
FYN 1601	88	250	94	20.26	4.70	1.1	18	39	14 563.5	80	0.728 58
Caitiannuo 1958	92	257	122	22.95	4.90	1.4	14	42	17 193.0	88	0.634 22
Jindannuo 41(CK)	86	223	94	20.53	4.90	1.1	16	37	14 326.5	81	0.714 39
Xinnuo 8608	93	268	119	22.36	5.00	1.3	14	45	16 345.5	81	0.658 12
Cainuo No.5	93	269	128	20.19	5.10	0.8	14	42	17 716.5	83	0.882 34
Heitiannuo 631	93	263.7	128.3	19.60	5.29	0.7	18	42	16 735.5	87	0.985 44
Heitiannuo No.2	85	227	81	20.66	4.60	0.7	16	39	13 999.5	80	0.957 46
ω_i	0.013 531 527	0.008 465 000	0.008 182 000	0.033 445 000	0.018 396 000	0.667 866 000	0.105 752 000	0.053 005 000	0.077 568 000	0.013 789 000	

3.3 Decision matrices and information entropy calculation of various traits According to formulas (1) to (3), the decision matrix R of each variety was obtained. According to formula (6), the normalization matrix R' of each variety was calculated. According to formula (7), the information entropy E_j and weight ω_i of each trait were calculated. The information entropies of the ten traits were $E_1 = 0.999\ 7$, $E_2 = 0.999\ 8$, $E_3 = 0.999\ 8$, $E_4 = 0.999\ 3$, $E_5 = 0.999\ 6$, $E_6 = 0.985\ 1$, $E_7 = 0.997\ 6$, $E_8 = 0.998\ 8$, $E_9 = 0.998\ 3$, $E_{10} = 0.999\ 7$.

$$R = \begin{bmatrix} 0.965\ 909\ 091 & 1 & 1 & 0.851\ 416 & 0.945\ 180 & 0.777\ 778 & 0.888\ 889 & 0.800\ 000 & 0.850\ 478 & 0.965\ 903 \\ 0.965\ 909\ 091 & 1 & 1 & 0.882\ 789 & 0.888\ 469 & 0.636\ 364 & 1 & 0.866\ 667 & 0.822\ 030 & 0.909\ 091 \\ 0.923\ 913\ 043 & 1 & 0.983\ 607 & 1 & 0.926\ 276 & 0.500\ 000 & 0.777\ 778 & 0.933\ 333 & 0.970\ 451 & 1 \\ 0.988\ 372\ 093 & 0.929\ 167 & 1 & 0.894\ 553 & 0.926\ 276 & 0.636\ 364 & 0.888\ 889 & 0.822\ 222 & 0.808\ 653 & 0.920\ 455 \\ 0.913\ 978\ 495 & 1 & 1 & 0.974\ 292 & 0.945\ 180 & 0.538\ 462 & 0.777\ 778 & 1 & 0.922\ 615 & 0.920\ 455 \\ 0.913\ 978\ 495 & 1 & 0.937\ 500 & 0.879\ 739 & 0.964\ 083 & 0.875\ 000 & 0.777\ 778 & 0.933\ 333 & 1 & 0.943\ 182 \\ 0.913\ 978\ 495 & 1 & 0.935\ 808 & 0.854\ 031 & 1 & 1 & 1 & 0.933\ 333 & 0.944\ 628 & 0.988\ 636 \\ 1 & 0.945\ 838 & 1 & 0.900\ 218 & 0.869\ 565 & 1 & 0.888\ 889 & 0.866\ 667 & 0.790\ 176 & 0.909\ 091 \end{bmatrix}$$

$$R' = \begin{bmatrix} 0.127\ 327\ 201 & 0.126\ 984 & 0.127\ 285 & 0.117\ 647 & 0.126\ 614 & 0.130\ 413 & 0.126\ 984 & 0.111\ 801 & 0.119\ 633 & 0.127\ 820 \\ 0.127\ 327\ 201 & 0.126\ 984 & 0.127\ 285 & 0.121\ 982 & 0.119\ 018 & 0.106\ 701 & 0.142\ 857 & 0.121\ 118 & 0.115\ 632 & 0.120\ 301 \\ 0.121\ 791\ 236 & 0.126\ 984 & 0.125\ 198 & 0.138\ 178 & 0.124\ 082 & 0.083\ 837 & 0.111\ 111 & 0.130\ 435 & 0.136\ 509 & 0.132\ 331 \\ 0.130\ 288\ 299 & 0.117\ 989 & 0.127\ 285 & 0.123\ 608 & 0.124\ 082 & 0.106\ 701 & 0.126\ 984 & 0.114\ 907 & 0.113\ 750 & 0.121\ 805 \\ 0.120\ 481\ 653 & 0.126\ 984 & 0.127\ 285 & 0.134\ 626 & 0.126\ 614 & 0.090\ 286 & 0.111\ 111 & 0.139\ 752 & 0.129\ 780 & 0.121\ 805 \\ 0.120\ 481\ 653 & 0.126\ 984 & 0.119\ 329 & 0.121\ 561 & 0.129\ 147 & 0.146\ 714 & 0.111\ 111 & 0.130\ 435 & 0.140\ 666 & 0.124\ 812 \\ 0.120\ 481\ 653 & 0.126\ 984 & 0.119\ 050 & 0.118\ 008 & 0.133\ 958 & 0.167\ 674 & 0.142\ 857 & 0.130\ 435 & 0.132\ 877 & 0.130\ 827 \\ 0.131\ 821\ 103 & 0.120\ 106 & 0.127\ 285 & 0.124\ 390 & 0.116\ 485 & 0.167\ 674 & 0.126\ 944 & 0.121\ 118 & 0.111\ 153 & 0.120\ 301 \end{bmatrix}$$

3.4 Comprehensive evaluation of the tested varieties According to the formula (5), the comprehensive evaluation value of each variety was calculated (Table 1). As shown in Table 1, the performance of comprehensive traits of the tested maize varieties was in the order Heitiannuo 631, Heitiannuo No. 2, Caunuo No. 5, Xinnuo 8601, FYN 1601, Xinnuo 8608, Jindannuo 41, Caitiannuo 1958 (from good to poor). As shown in Table 1, among the tested maize varieties, Heitiannuo 631, Heitiannuo No. 2 and Cainuo No. 5 are excellent varieties, and the rest are good varieties. At the same time, Jindannuo 41 is still a good variety and can be used as a control variety in the regional trials of sweet-glutinous maize.

4 Discussion

Regarding on the research on the comprehensive evaluation method of crop variety, the predecessors have done a lot of work[3-6]. However, in the evaluation process, there is a subjective limitation that the weight of traits is assigned artificially. The use of the entropy weight method further improves the reliability of the regional test results. The tested sweet-glutinous maize varieties in the regional trials of Shanxi Province basically represent the overall level of sweet-glutinous maize breeding in Shanxi Province. The comprehensive analysis by entropy weight method shows that the comprehensive traits of the sweet-glutinous maize varieties tested in Shanxi Province in 2016 were generally at a good level. It shows that the breeding level of sweet-glutinous maize in Shanxi Province has been continuously improved on the basis of the original, and in particular, the breeding of Heitiannuo maize varieties has reached a high level. In this study, the fertility characteristics, yield and other traits of new sweet-glutinous maize varieties were evaluated using the entropy weight method, but the quality and ease of processing of these varieties were not mentioned. In the future, the selection and comprehensive evaluation of new sweet-glutinous varieties should consider more traits according to the different consumption needs of the market. At the same time, a variety of different evaluation methods should be adopted, in order to make a more scientific and effective comprehensive analysis and judgment.

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