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Comprehensive Analysis and Evaluation of New Flue-cured Tobacco Varieties in Sichuan Regional Trials

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Abstract Analytic hierarchy process (AHP) was used to distribute the weight of 10 evaluation indexes of flue-cured tobacco varieties of regional trials in Sichuan province in 2016 for dynamic technique for order preference by similarity to ideal solution (DTOPSIS), membership function was used for optimizing dimensionless treatment of chemical evaluation indexes of DTOPSIS, and then DTOPSIS was used for comprehensive evaluation of varieties. The weight of yield, proportion of superior tobacco, output value, leaf number, stem circumference, plant height, nicotine content, total sugar content, potassium content and black shank disease index was 0.090 2, 0.235 1, 0.301 4, 0.035 1, 0.021 7, 0.021 7, 0.057 1, 0.035 1, 0.035 1 and 0.167 6, respectively. The comprehensive evaluation order of new varieties in planting areas in Southwest Sichuan was ‘Yunyan87’>‘SCT01’>‘Hongda’>‘K326’>‘09011’>‘X4’>‘X3’, the order in South Sichuan was ‘K326’>‘Yunyan87’>‘09011’>‘SCT01’>‘X3’>‘X4’, and the order in North Sichuan was ‘09011’>‘Yunyan87’>‘X4’>‘SCT01’>‘X3’. The results of this study show that further experiments and demonstrations of ‘SCT01’ could be conducted in plant areas in Southwest Sichuan, '09011' has the potential to be used as a good variety in plant areas in North Sichuan, and the corresponding cultivation measures of ‘X3’ and ‘X4’ should be improved. This research would provide scientific basis for the screening, identification and promotion of new flue-cured tobacco varieties, and enrich the evaluation system of new flue-cured tobacco varieties.

Keywords DTOPSIS; AHP; Membership function; New flue-cured tobacco varieties; Regional trials

Under different environmental conditions, the expression patterns of specific genes in the same plant are different (Ren et al., 2019; Yuan et al., 2019), which is one of the main reasons for the obvious differences in traits. Therefore, the comprehensive evaluation of crop varieties in different ecological planting areas is an effective way to promote new varieties. Planting areas of Sichuan flue-cured tobacco can be divided into Southwest Sichuan (Liangshan Prefecture and Panzhihua City), South Sichuan (Luzhou City and Yibin City) and North Sichuan (Guangyuan City) (Zeng et al., 2019). Southwest Sichuan tobacco area mainly belongs to subtropical monsoon climate, and the main dominant varieties are 'Yunyan87', 'Hongda' and 'K326'. Southern Sichuan tobacco area mainly belongs to subtropical humid climate, and the main dominant varieties are 'Yunyan87' and 'K326'. Northern Sichuan tobacco area mainly belongs to subtropical humid monsoon climate, and the main dominant varieties are 'Yunyan87'.

DTOPSIS (Dynamic technique for order preference by similarity to ideal solution) can be used to solve the problem of multi-index evaluation and sequencing, and it has been one of the important methods for comprehensive evaluation of crop varieties. At present, DTOPSIS has been successfully used in the comprehensive evaluation of Maize (*Zea mays* L.) (Song et al., 2020), cotton (*Gossypium* spp.) (Ma et al., 2015) and other crops, and also reported in the comprehensive evaluation of tobacco (*Aconitum carmichaeli* Debx.) (Sun et al., 2012; Zhou et al., 2012; Yao et al., 2020). This evaluation system needs to determine the weight of each evaluation index, but most of the predecessors used subjective empirical valuation method and expert method, which led to the lack of scientific basis for the weight allocation (Wu et al., 2012). In addition, DTOPSIS commonly uses the optimal value of dimensionless

treatment of nicotine, total sugar, kalium and other neutral indicators with appropriate range (Sun et al., 2012; Zhou et al., 2012), which leads to the reduction of the evaluation index grade within the appropriate range and affects the comprehensive evaluation results. If the membership function is used to nondimensionalize these neutral indexes, more scientific and accurate results can be obtained (Yao et al., 2020). Analytical hierarchy process (AHP) is a weight distribution method combining qualitative analysis and quantitative analysis, which is widely used in comprehensive evaluation of varieties (Wu et al., 2012; Ma et al., 2019) and comprehensive evaluation of quality and safety (Wang et al., 2017).

The goal of Sichuan flue-cured tobacco breeding is high quality and disease resistance. In 2016, Industrial Crops Research Institute, Sichuan Academy of Agricultural Sciences, Sichuan Institute of Tobacco Science, etc. carried out popularization identification of new flue-cured tobacco varieties in three flue-cured tobacco ecological regions of Sichuan according to the requirements of national tobacco regional test. It is generally the comprehensive character performance rather than the single index that determines the extension of new varieties. Therefore, AHP was used to provide scientific and reasonable weights for DTOPSIS method, membership function was used for optimizing dimensionless treatment of chemical evaluation indexes of DTOPSIS, and then DTOPSIS was used for comprehensive evaluation of varieties. This research would provide scientific basis for the screening, identification and promotion of new flue-cured tobacco varieties.

1 Results and Analysis

1.1 Weight analysis

1.1.1 Construction of judgment matrix

After fully soliciting the opinions of tobacco breeding, cultivation, plant protection experts, and combining with the existing references on comprehensive evaluation of tobacco (Sun et al., 2012; Zhou et al., 2012; Yao et al., 2020), 10 indexes including yield, proportion of superior tobacco, output, leaf number, stem circumference, plant height, nicotine content, total sugar content, kalium content and black shank index were selected as comprehensive evaluation indexes. The 1~9 comparison scale method proposed by SATTY was used to compare each index in pairs (Deng, 2018, Zhejiang University, pp.27-32; Li et al., 2019), and the judgment matrix *A* (Table 1) was constructed.

1.1.2 Calculation and test of weight vector

According to AHP theory, the weights can be assigned by square root method, sum product method, characteristic root method and logarithmic least square method (Wu et al., 2012). AHP is a general method of multi-index weight distribution, which is widely used in variety comprehensive evaluation (Wu et al., 2012; Ma et al., 2019). In this study, the square root method was used to calculate the weight vector and carry out the consistency test (Table 2). The calculation process is as follows: (1) Multiply the factors in each row of judgment matrix *A* to get the vector $M_i=[M_1\ M_2\ M_3\ \cdots\cdots M_n]^T$, and the calculation formula is $M_i=\prod_{j=1}^{n}X_{ij}, i=1,2,3,\ldots\ldots n$. (2) Vector $\overline{M}_i=[\overline{M}_1\ \overline{M}_2\ \overline{M}_3\ \cdots\cdots\ \overline{M}_n]^T$ is calculated by formula $\overline{M_i}=\sqrt[n]{M_i}$. (3) Normalize the vector $\overline{M}_1$ to get the weight vector W_i, and the calculation formula is $W_i=\overline{M}_i/\sum^{n}{}_{i=1}\overline{M}_i$.

1.1.3 Consistency test

(1) Maximum eigenvalue of judgment matrix *A* $\lambda\frac{1}{n}\sum_{i=1}^{n}\frac{AW_i}{W_i}{}_{max}$. (2) General consistency index of judgment matrix $CI=\lambda_{max}/(n-1)$. (3) Consistency ratio $CR=CI/RI$, the RI value of 10 order matrix is 1.49. CR=0.016 9<0.1, the judgment matrix is consistent, and the weight distribution of evaluation index is reasonable (Wu et al., 2012; Deng, 2018, Zhejiang University, pp.27-32; Li et al., 2019).

Table 1 Judgment matrix *A*

Indexes	Yield (kg/hm^2)	Proportion of superior tobacco (%)	Output (yuan/hm^2)	Number of leave (piece)	Stem circum-ference (cm)	Plant height (cm)	Nicotine content (%)	Total sugar content (%)	Kalium content (%)	Black shank index
Yield (kg/hm^2)	1	1/3	1/5	3	4	4	2	3	3	1/2
Proportion of superior tobacco (%)	3	1	1/2	7	9	9	5	7	7	2
Output (yuan/hm^2)	5	2	1	7	9	9	6	7	7	3
Number of leave (piece)	1/3	1/7	1/7	1	2	2	1/2	1	1	1/6
Stem circumference (cm)	1/4	1/9	1/9	1/2	1	1	1/3	1/2	1/2	1/7
Plant height (cm)	1/4	1/9	1/9	1/2	1	1	1/3	1/2	1/2	1/7
Nicotine content (%)	1/2	1/5	1/6	2	3	3	1	2	2	1/4
Total sugar content (%)	1/3	1/7	1/7	1	2	2	1/2	1	1	1/6
Kalium content (%)	1/3	1/7	1/7	1	2	2	1/2	1	1	1/6
Black shank index	2	1/2	1/3	6	7	7	4	6	6	1

Note: The content of total sugar and potassium is expressed by mass percentage (Yao et al., 2020)

Table 2 Related data of weight vector calculation

Indexes	M_i	W_i	AW_i
Yield (kg/hm^2)	1.399 4	0.090 2	0.915 8
Proportion of superior tobacco (%)	3.647 4	0.235 1	2.403 6
Output (yuan/hm^2)	4.676 3	0.301 4	3.194 6
Number of leave (piece)	0.543 9	0.035 1	0.355 1
Stem circumference (cm)	0.336 1	0.021 7	0.221 1
Plant height (cm)	0.336 1	0.021 7	0.221 1
Nicotine content (%)	0.886 6	0.057 1	0.581 8
Total sugar content (%)	0.543 9	0.035 1	0.355 1
Kalium content (%)	0.543 9	0.035 1	0.355 1
Black shank index	2.599 9	0.167 6	1.729 0

1.2 Construction of evaluation matrix *B*

The evaluation matrix *B* (Table 3) was constructed by taking the average value of each index data of Liangshan Prefecture and Panzhihua City as the data of planting area in Southwest Sichuan, taking the average value of each index data of Luzhou City and Yibin City as the data of planting area in South Sichuan, and taking the data of Guangyuan City as the data of planting area in North Sichuan.

Table 3 Evaluation matrix *B*

Planting areas	Variety	Yield (kg/hm^2)	Proportion of superior tobacco (%)	Output (yuan/hm^2)	Number of leave (piece)	Stem circumference (cm)	Plant height (cm)	Nicotine content (%)	Total sugar content (%)	Kalium content (%)	Black shank index
Planting areas in Southwest Sichuan	09011	2 353.50	25.83	43 257.33	18.95	11.45	117.95	2.89	27.39	1.85	3.32
	X3	2 095.50	24.69	40 254.56	17.55	11.55	111.10	2.68	30.01	2.25	4.97
	X4	2 035.50	28.13	41 381.72	17.20	12.00	111.95	2.56	28.91	2.11	4.81
	SCT01	2 190.75	33.79	47 254.48	18.20	11.60	108.65	2.37	26.71	2.24	2.98
	k326	2 118.75	28.87	42 841.13	18.70	10.40	102.50	2.60	26.96	1.98	2.86
	Yunyan87	2 027.25	32.89	46 282.12	17.50	10.05	108.90	2.37	25.14	2.02	2.31
	Hongda	1 857.00	38.76	43 602.36	14.70	11.40	109.00	2.26	27.92	2.49	3.90
Planting areas in South Sichuan	09011	2 158.50	31.06	45 134.24	19.25	9.75	114.75	2.98	26.25	1.98	2.82
	X3	1 995.75	26.41	36 143.03	19.60	10.30	106.45	2.55	25.84	2.52	5.64
	X4	2 033.25	25.40	38 204.77	17.15	9.75	98.70	2.87	26.98	2.41	5.21
	SCT01	2 071.50	28.19	41 782.16	19.00	9.90	105.00	2.29	27.25	2.21	2.26
	k326	2 132.25	28.81	45 608.83	18.50	9.45	107.80	2.48	25.46	2.45	0.78
	Yunyan87	1 843.50	34.29	42 160.85	17.00	9.70	90.50	2.37	28.07	2.30	1.99
Planting areas in North Sichuan	09011	1 494.00	18.36	25 263.54	16.30	8.20	63.60	2.61	27.34	1.98	8.61
	X3	1 474.50	16.34	22 471.38	15.80	8.60	65.50	2.49	28.87	2.21	16.06
	X4	1 242.00	18.10	19 983.78	14.60	8.20	55.00	2.86	26.95	2.29	12.70
	SCT01	1 399.50	17.92	22 853.84	16.20	7.90	60.80	2.38	27.89	2.33	19.73
	Yunyan87	1 263.00	20.45	22 872.93	16.20	7.40	67.60	2.35	26.98	2.05	10.29

1.3 Dimensionless treatment of evaluation index

Yield, proportion of superior tobacco, output, leaf number and stem circumference were positive indicators, plant height and black shank index were negative indicators, and nicotine content, total sugar content and kalium content were neutral indicators (Sun et al., 2012; Zhou et al., 2012; Yao et al., 2020). Positive indicators were nondimensionalized with $Z_{ij}=b_{ij}/b_{jmax}$, and negative indicators were nondimensionalized with $Z_{ij}=b_{jmin}/b_{ij}$. Parabolic membership function P(x) was used for optimizing dimensionless treatment of nicotine and total sugar content (The lower critical value x_1 of total sugar and nicotine was 10 and 1, respectively; Upper critical value x_2 was 35 and 3.5, respectively; The optimal lower critical value x_3 was 20 and 2, respectively; The optimal upper critical value x_4 was 28 and 2.5, respectively) (Yao et al., 2020). S-type membership function S(x) was used for optimizing dimensionless treatment of kalium content (The lower critical value x_1 was 1, and upper critical value x_2 was 2.5) (Yao et al., 2020). The calculation formulas were ① and ② respectively. The evaluation matrix *B* was divided into planting areas and normalized matrix *Z* was obtained after dimensionless treatment (Table 4).

$$P(x)=\begin{cases}0.1x<x_1,x>x_2\\0.9(x-x_1)/(x_3-x_1)+0.1x_1\le x<x_3\\1x_3\le x\le x_4\\1-0.9(x-x_4)/(x_2-x_4)x_4<x\le x_2\end{cases}\quad ①$$

$$S(x)=\begin{cases}1x>x_2\\0.9(x-x_1)/(x_2-x_1)+0.1x_1\le x\le x_2\\0.1x<x_1\end{cases}\quad ②$$

1.4 Calculation of decision matrix *R*

The weight value W_j (Table 2) of each index was multiplied by the *j* column in the normalized matrix *Z* to obtain the decision matrix *R* (Table 5).

Table 4 Normalized matrix *Z*

Planting areas	Variety	Yield (kg/hm^2)	Proportion of superior tobacco (%)	Output (yuan/hm^2)	Number of Leave (piece)	Stem circumference (cm)	Plant height (cm)	Nicotine content (%)	Total sugar content (%)	Kalium content (%)	Black shank index
Planting areas in Southwest Sichuan	09011	1.000 0	0.666 4	0.915 4	1.000 0	0.954 2	0.869 0	0.649 0	1.000 0	0.610 0	0.695 8
	X3	0.890 4	0.637 0	0.851 9	0.926 1	0.962 5	0.922 6	0.838 0	0.741 6	0.850 0	0.464 8
	X4	0.864 9	0.725 7	0.875 7	0.907 7	1.000 0	0.915 6	0.946 0	0.883 0	0.766 0	0.480 2
	SCT01	0.930 8	0.871 8	1.000 0	0.960 4	0.966 7	0.943 4	1.000 0	1.000 0	0.844 0	0.775 2
	k326	0.900 3	0.744 8	0.906 6	0.986 8	0.866 7	1.000 0	0.910 0	1.000 0	0.688 0	0.807 7
	Yunyan87	0.861 4	0.848 6	0.979 4	0.923 5	0.8375	0.941 2	1.000 0	1.000 0	0.712 0	1.000 0
	Hongda	0.789 0	1.000 0	0.922 7	0.775 7	0.950 0	0.940 4	1.000 0	1.000 0	0.994 0	0.592 3
Planting areas in South Sichuan	09011	1.000 0	0.905 8	0.989 6	0.982 1	0.946 6	0.788 7	0.568 0	1.000 0	0.688 0	0.276 6
	X3	0.924 6	0.770 2	0.792 5	1.000 0	1.000 0	0.850 2	0.955 0	1.000 0	1.000 0	0.138 3
	X4	0.942 0	0.740 7	0.837 7	0.875 0	0.946 6	0.916 9	0.667 0	1.000 0	0.946 0	0.149 7
	SCT01	0.959 7	0.822 1	0.916 1	0.969 4	0.961 2	0.861 9	1.000 0	1.000 0	0.826 0	0.345 1
	k326	0.987 8	0.840 2	1.000 0	0.943 9	0.917 5	0.839 5	1.000 0	1.000 0	0.970 0	1.000 0
	Yunyan87	0.854 1	1.000 0	0.924 4	0.867 3	0.941 7	1.000 0	1.000 0	0.991 0	0.880 0	0.392 0
Planting areas in North Sichuan	09011	1.000 0	0.897 8	1.000 0	1.000 0	0.953 5	0.864 8	0.901 0	1.000 0	0.688 0	1.000 0
	X3	0.986 9	0.799 0	0.889 5	0.969 3	1.000 0	0.839 7	1.000 0	0.888 1	0.826 0	0.536 1
	X4	0.831 3	0.885 1	0.791 0	0.895 7	0.953 5	1.000 0	0.676 0	1.000 0	0.874 0	0.678 0
	SCT01	0.936 7	0.876 3	0.904 6	0.993 9	0.918 6	0.904 6	1.000 0	1.000 0	0.898 0	0.436 4
	Yunyan87	0.845 4	1.000 0	0.905 4	0.993 9	0.860 5	0.813 6	1.000 0	1.000 0	0.730 0	0.836 7

Table 5 Decision matrix *R*

Planting areas	Variety	Yield (kg/hm^2)	Proportion of superior tobacco (%)	Output (yuan/hm^2)	Number of leave (piece)	Stem circumference (cm)	Plant height (cm)	Nicotine content (%)	Total sugar content (%)	Kalium content (%)	Black shank index
Planting areas in Southwest Sichuan	09011	0.090 2	0.156 7	0.275 9	0.035 1	0.020 7	0.018 9	0.037 1	0.035 1	0.021 4	0.116 6
	X3	0.080 3	0.149 8	0.256 8	0.032 5	0.020 9	0.020 0	0.047 8	0.026 0	0.029 8	0.077 9
	X4	0.078 0	0.170 6	0.263 9	0.031 9	0.021 7	0.019 9	0.054 0	0.031 0	0.026 9	0.080 5
	SCT01	0.084 0	0.205 0	0.301 4	0.033 7	0.021 0	0.020 5	0.057 1	0.035 1	0.029 6	0.129 9
	k326	0.081 2	0.175 1	0.273 3	0.034 6	0.018 8	0.021 7	0.052 0	0.035 1	0.024 1	0.135 4
	Yunyan87	0.077 7	0.199 5	0.295 2	0.032 4	0.018 2	0.020 4	0.057 1	0.035 1	0.025 0	0.167 6
	Hongda	0.071 2	0.235 1	0.278 1	0.027 2	0.020 6	0.020 4	0.057 1	0.035 1	0.034 9	0.099 3
Planting areas in South Sichuan	09011	0.090 2	0.213 0	0.298 3	0.034 5	0.020 5	0.017 1	0.0324	0.035 1	0.024 1	0.046 4
	X3	0.083 4	0.181 1	0.238 8	0.035 1	0.021 7	0.018 4	0.0545	0.035 1	0.035 1	0.023 2
	X4	0.085 0	0.174 1	0.252 5	0.030 7	0.020 5	0.019 9	0.0381	0.035 1	0.033 2	0.025 1
	SCT01	0.086 6	0.193 3	0.276 1	0.034 0	0.020 9	0.018 7	0.0571	0.035 1	0.029 0	0.057 8
	k326	0.089 1	0.197 5	0.301 4	0.033 1	0.019 9	0.018 2	0.0571	0.035 1	0.034 0	0.167 6
	Yunyan87	0.077 0	0.235 1	0.278 6	0.030 4	0.020 4	0.021 7	0.0571	0.034 8	0.030 9	0.065 7
Planting areas in North Sichuan	09011	0.090 2	0.211 1	0.301 4	0.035 1	0.020 7	0.018 8	0.0514	0.035 1	0.024 1	0.167 6
	X3	0.089 0	0.187 9	0.268 1	0.034 0	0.021 7	0.018 2	0.0571	0.031 2	0.029 0	0.089 9
	X4	0.075 0	0.208 1	0.238 4	0.031 4	0.020 7	0.021 7	0.0386	0.035 1	0.030 7	0.113 6
	SCT01	0.084 5	0.206 0	0.272 7	0.034 9	0.019 9	0.019 6	0.0571	0.035 1	0.031 5	0.073 1
	Yunyan87	0.076 3	0.235 1	0.272 9	0.034 9	0.018 7	0.017 7	0.0571	0.035 1	0.025 6	0.140 2

1.5 Calculation of "ideal solutions" and "negative ideal solutions"

According to formula $X^+=(maxr_{i1}\ maxr_{i2}\ \cdots\cdots\ maxr_{ij})$, calculated the "ideal solution" by planting area, and formed the "ideal solutions" matrix X^+ (Table 6). According to formula $X^-=(minr_{i1}\ minr_{i2}\ \cdots\cdots\ minr_{ij})$, calculated the "negative ideal solution" by planting area, and formed the "negative ideal solution" matrix X^- (Table 7).

Table 6 "Ideal solutions" matrix X^+

Planting areas	Yield (kg/hm^2)	Proportion of superior tobacco (%)	Output (yuan/hm^2)	Number of leave (piece)	Stem circumference (cm)	Plant height (cm)	Nicotine content (%)	Total sugar content (%)	Kalium content (%)	Black shank index
Planting areas in Southwest Sichuan	0.090 2	0.235 1	0.301 4	0.035 1	0.021 7	0.021 7	0.057 1	0.035 1	0.034 9	0.167 6
Planting areas in South Sichuan	0.090 2	0.235 1	0.301 4	0.035 1	0.021 7	0.021 7	0.057 1	0.035 1	0.035 1	0.167 6
Planting areas in North Sichuan	0.090 2	0.235 1	0.301 4	0.035 1	0.021 7	0.021 7	0.057 1	0.035 1	0.031 5	0.167 6

Table 7 "Negative ideal solutions" matrix X^-

Planting areas	Yield (kg/hm^2)	Proportion of superior tobacco (%)	Output (yuan/hm^2)	Number of leave (piece)	Stem circumference (cm)	Plant height (cm)	Nicotine content (%)	Total sugar content (%)	Kalium content (%)	Black shank index
Planting areas in Southwest Sichuan	0.071 2	0.149 8	0.256 8	0.027 2	0.018 2	0.018 9	0.037 1	0.026 0	0.021 4	0.077 9
Planting areas in South Sichuan	0.077 0	0.174 1	0.238 8	0.030 4	0.019 9	0.017 1	0.032 4	0.034 8	0.024 1	0.023 2
Planting areas in North Sichuan	0.075 0	0.187 9	0.238 4	0.031 4	0.018 7	0.017 7	0.038 6	0.031 2	0.024 1	0.073 1

1.6 Calculation of distance between varieties and "ideal solution" and "negative ideal solution"

Euclidean norm was used to calculate the distances between varieties and "ideal solution" and "negative ideal solution" (Sun et al., 2012; Zhou et al., 2012; Yao et al., 2020). The calculation formulas were ③ and ④ respectively, and the calculation results were showed in the Table 8.

$$S^+ = \left[\sum_{j=1}^{n} (R_{ij} - X_j^+)^2\right]^{\frac{1}{2}} i = 1,2,3,\ldots\ldots,m \quad ③$$

$$S^- = \left[\sum_{j=1}^{n} (R_{ij} - X_j^-)^2\right]^{\frac{1}{2}} i = 1,2,3,\ldots\ldots,m \quad ④$$

1.7 Calculation of relative approximation

According to formula⑤, the approximate degree between the tested varieties and the "ideal solution" was calculated.

$$C_i = S_i^-/(S_i^+ + S_i^-) i = 1,2,3,\ldots\ldots m \quad ⑤$$

1.8 Comprehensive analysis of evaluation results

According to the order of C_i, the maximum is the best variety for comprehensive evaluation. The comprehensive evaluation order of new varieties in planting areas in Southwest Sichuan was ‘Yunyan87’>‘SCT01’>‘Hongda’>‘K326’>‘09011’>‘X4’>‘X3’. The comprehensive evaluation result of 'SCT01' was worse than that of 'Yunyan87', but better than that of ‘Hongda’ and 'K326', which indicated that further experiments and demonstrations of ‘SCT01’ could be conducted in plant areas in Southwest Sichuan. The comprehensive evaluation results of '09011', 'X3' and 'X4' were worse than those of 'Yunyan87', ‘Hongda’ and 'K326', which indicated that the cultivation measures of '09011', 'X3' and 'X4' should be improved in Southwest Sichuan.The order in South Sichuan was ‘K326’>‘Yunyan87’>‘09011’>‘SCT01’>‘X3’>‘X4’. The comprehensive

evaluation results of all the new varieties were worse than those of the control varieties, which indicated that the cultivation measures of all the new varieties should be improved in South Sichuan. The order in North Sichuan was '09011'>'Yunyan87'>'X4'>'SCT01'>'X3'. The comprehensive evaluation of '09011' was better than that of 'Yunyan87', which indicated that further experiments and demonstrations of '09011' could be conducted in plant areas in northern Sichuan. The comprehensive evaluation of 'SCT01', 'X3' and 'X4' was inferior to that of 'Yunyan87', which indicated that the cultivation measures of 'SCT01', 'X3' and 'X4' should be improved in northern Sichuan.

Table 8 Comprehensive evaluation

Planting areas	Variety	S^+	S^-	C_i	Ranking of comprehensive evaluation	Output (yuan/hm^2)	Output value ranking
Planting areas in Southwest Sichuan	09011	0.100 0	0.049 3	0.330 1	5	43 257.33	4
	X3	0.132 8	0.017 5	0.116 7	7	40 254.56	7
	X4	0.115 8	0.030 3	0.207 4	6	41 381.72	6
	SCT01	0.049 0	0.092 3	0.653 2	2	47 254.48	1
	k326	0.075 2	0.068 5	0.476 6	4	42 841.13	5
	Yunyan87	0.039 8	0.112 1	0.738 1	1	46 282.12	2
	Hongda	0.075 1	0.094 2	0.556 4	3	43 602.36	3
Planting areas in South Sichuan	09011	0.126 3	0.075 9	0.375 4	3	45 134.24	2
	X3	0.166 6	0.026 9	0.139 0	5	36 143.03	6
	X4	0.163 8	0.019 4	0.105 6	6	38 204.77	5
	SCT01	0.120 4	0.060 8	0.335 5	4	41 782.16	4
	k326	0.037 9	0.161 8	0.810 4	1	45 608.83	1
	Yunyan87	0.105 4	0.088 2	0.455 5	2	42 160.85	3
Planting areas in North Sichuan	09011	0.025 9	0.117 7	0.819 4	1	25 263.54	1
	X3	0.097 1	0.041 7	0.300 5	5	22 471.38	4
	X4	0.090 6	0.046 1	0.337 4	3	19 983.78	5
	SCT01	0.103 1	0.045 0	0.303 6	4	22 853.84	3
	Yunyan87	0.042 6	0.091 1	0.681 2	2	22 872.93	2

2 Discussion

Comprehensive evaluation of varieties is an important link in breeding. DTOPSIS is a new general method for comprehensive evaluation, which is widely used in recent years. It uses the relative approximation between varieties and ideal solution to quantify the comprehensive characteristics of varieties, overcomes the subjectivity of previous comprehensive evaluation, and has been widely used in the comprehensive evaluation of crop varieties (Li et al., 2018). The key to the application of DTOPSIS lies in the weight distribution and dimensionless treatment of each character. When determining the weight value of each evaluation character, for the same crop with basically the same breeding goal, different researchers often give different weight values according to their own experience, which has a certain degree of subjective randomness (Wu et al., 2012). When DTOPSIS method was used to deal with neutral indexes with the most suitable range, such as total sugar, nicotine and kalium, the optimal value was generally used for dimensionless treatment, resulting in the reduction of neutral index grade within the suitable range. For example, it is generally considered that the optimal range of nicotine is 2~2.5% (Sun et al., 2012; Zhou et al., 2012; Yao et al., 2020), while the optimal value is 2.5% (Sun et al., 2012; Zhou et al., 2012) according to DTOPSIS method. When the nicotine content of 2% and 2.5% was nondimensionalized, the data may be significantly different, and this significant difference can be transmitted to the final evaluation results, but in fact, both of them are in the optimal range of nicotine, so there should be no significant difference after dimensionless treatment. Yao et al. (2020) introduced parabolic membership function to deal with nicotine and total sugar content dimensionless and introduced S-type membership function to deal with potassium content dimensionless, so that the evaluation results in the optimal range were the same and obtained more accurate evaluation results.

This study combines the existing mature evaluation methods AHP and DTOPSIS, and makes partial optimization on the dimensionless link of DTOPSIS with reference to the research results of Yao et al. (2020). The comprehensive evaluation ranking results are basically consistent with the traditional ranking results with the output value as the goal. The results of this study are based on one year's regional test data, using the optimized combination evaluation method to carry out comprehensive evaluation. The universality of the evaluation method in the comprehensive evaluation of flue-cured tobacco, and the verifiability of the evaluation results need to be further studied.

3 Materials and Methods

3.1 Experiment materials

In 2016, project team of flue-cured tobacco varieties in Sichuan regional trials arranged the regional test of flue-cured tobacco at five test sites in Liangshan Prefecture, Panzhihua City, Luzhou City, Yibin City and Guangyuan City (Table 9). After fully soliciting the opinions of tobacco breeding, cultivation, plant protection experts, 10 indexes including yield, proportion of superior tobacco, output, leaf number, stem circumference, plant height, nicotine content, total sugar content, kalium content and black shank index in 2016 regional test sites were selected as comprehensive evaluation indexes. 2016 new flue-cured tobacco varieties in Sichuan regional trials were ‘09011’, ‘X3’, ‘X4’ and ‘SCT01’. 'Yunyan87', 'K326' and 'Hongda' were selected as control varieties in Liangshan experimental site. 'Yunyan87' and 'K326' were selected as control varieties in Panzhihua, Luzhou and Yibin City. 'Yunyan87' was selected as the control variety in Guangyuan experimental site. The plot area of the experimental site was 48 m^2, and the plots were randomly arranged with three repetitions. Yunyan87 was cultivated around the plot as a protective row. All vrieties were managed according to the local tobacco standardized production technology.

Table 9 Distribution of experimental locations of new flue-cured tobacco varieties in Sichuan

Planting areas	Experimental locations of regional trials
Planting areas in Southwest Sichuan	Yimen Town, Huili County, Liangshan prefecture
	Pingdi Town, Renhe district, Panzhihua City
Planting areas in South Sichuan	Dazhai Township, Gulin County, Luzhou City
	Daba Township, Xingwen County, Yibin City
Planting areas in North Sichuan	Pu'an Town, Jiange County, Guangyuan City

3.2 Evaluation index and determination method

The proportions of superior tobacco and output were calculated according to the 42-grade national standard classification method (Zhou et al., 2012). The leaf number, stem circumference and plant height were determined with YC/T142-2010. The disease index was determined with GB/T23222-2008. The contents of total sugar, nicotine and kalium content were determined by continuous flow analysis.

3.3 Evaluation method

After fully soliciting the opinions of tobacco breeding, cultivation, plant protection experts, and combining with the existing references on comprehensive evaluation of tobacco (Sun et al., 2012; Zhou et al., 2012; Yao et al., 2020), 10 indexes including yield, proportion of superior tobacco, output, leaf number, stem circumference, plant height, nicotine content, total sugar content, kalium content and black shank index were selected as comprehensive evaluation indexes. The comprehensive evaluation was mainly carried out according to the following 6 steps (Wu et al., 2012; Deng, 2018, Zhejiang University, pp.27-32). (1) AHP method was used to determine the weight of 10 evaluation indexes. (2) The evaluation matrix *B* was constructed by taking the average values of the index data of Liangshan, Panzhihua, Luzhou, and Yibin experimental sites. (3) DTOPSIS positive index model was used for dimensionless treatment of yield, proportion of superior tobacco, output value, leaf number and stem circumference. DTOPSIS negative index model was used to deal with plant height and black shank index. The total sugar content and nicotine content were treated by parabolic membership function. S-type membership function was used to deal with potassium content. Finally, the normalized matrix *Z* was obtained. (4) According to the weight determined by AHP method, the decision matrix *R* was calculated. (5) The "ideal solution" and "negative ideal solution" were calculated according to planting areas, and the distances between varieties and "ideal solution" and "negative ideal

solution" were calculated with Euclidean norm. (6) Calculated the approximate degree C_i between the tested varieties and the "ideal solution", and the size of C_i indicated the relative advantages and disadvantages among varieties.

Authors' contributions

DSD and YPS designed and carried out the study. HL and SYZ participated in the statistical analysis and drafted the manuscript. ZHL, CZH, LJ, ZQF, and JQP participated in the design of the study and results analysis. WSG conceived of the project, and directed the design of the study, data analysis, draft and revision. All authors read and approved the final manuscript.

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Reference

Gu S.L., Zhang G.X., Shi H.Z., Liu Q.H., Liu G.S., Wang T.X., and Li Y.T., 2011, Study on characteristics of newly introduced flue-cured tobacco varieties with strong aroma style in the middle Henan tobacco planting region, Zhongguo Yancao Kexue (Chinese Tobacco Science), 32(2): 11-16

Li C.Y., Lu G.B., Liu H., Guo X.D., and Liu Y.C., 2019, Comprehensive evaluation of Tuanzao by AHP and DTOPSIS method, Shanxi Nongye Kexue (Journal of Shanxi Agricultural Sciences), 47(12): 2057-2061

Li W.Y., Wei Y., Kong F.N., Luo P.S., Zhao J., Huang L.J., Jiang J.J., Zhuo F.C., and Zhou J., 2018, Study on comprehensive evaluation of strawberry varieties by DTOPSIS method, Zhiwu Shengli Xuebao (Plant Physiology Communications), 54(5): 925-930

Ma W.R., Fang W.M., Wang H.B., Zhang F., Chen S.M., Chen F.D., and Guan Z.Y., 2019, Establishment of appraisal system for the stem and branch characteristics and varieties evaluation of spray cut chrysanthemum, Zhongguo Nongye Kexue (Scientia Agricultura Sinica), 52(14): 2515-2524

Ma H., Dai L., Li Y.Q., Long C.Y., Zhao Y.P., Aimaierjiang A., Li J., and Liu Z.X., 2015, The application and comparison of gray relational analysis DTOPSIS method in the comprehensive evaluation of twice defoliation of machine picking-up cotton, Zhongguo Mianhua (China Cotton), 42(1): 19-21

Ren R., Zhang X.F., Hu W.T., Zhong L.M., Yu C., and Liu J.L., 2019, The response of Arabidopsis ANAC055 gene mutant to high salt and osmotic stress, Jiyinzuxue Yu Yingyong Shengwuxue (Genomics and Applied Biology), 38(2): 721-728

Song X.L., Wu Y., Yang X.L., Sun Y.J., Zhang L., Song B.G., Shen B.S., Wu J.Y., Ma D.Z., Hou Y.M., Wang Y.B., and Yang D.G., 2020, Comparison of entropy weighted DTOPSIS method and grey relational degree analysis in comprehensive evaluation of maize varieties, Yumi Kexue (Journal of Maize Sciences), 28(2): 41-46

Sun H., Li X.J., Ma H.B., Sun J.P., Ding Y.F., and Ping W.L., 2012, Comprehensive evaluation of new tobacco varieties with method of DTOPSIS, Xinan Nongye Xuebao (Southwest China Journal of Agricultural Sciences), 25(4): 1197-1200
https://doi.org/10.4028/www.scientific.net/AMM.313-314.1197

Wang M.J., Pei H.S., Sun J.S., Tan X.Y., Zhang X.Q., Sun T., Liu F.S., Xu Z.Y., Yang Y., and Chen Z., 2017, Comprehensive evaluation on quality and safety of *Ganoderma lucidum* based on improved analytic hierarchy process, Nongye Gongcheng Xuebao (Transactions of the Chinese Society of Agricultural Engineering), 33(4): 302-308

Wu J.T., Yang J.X., Liu F.Y., Li Q.W., Wu W.L., Pan F.Y., Xie J., and Chen Y.G., 2012, Application of AHP and DTOPSIS method in breeding of sugarcane variety, Guangdong Nongye Kexue (Guangdong Agricultural Sciences), 39(12): 26-29

Yao W., Xiang S.P., Zhou Q.M., and Li J., 2020, Evaluation of new flue-cured tobacco varieties in Hunan regional trial by DTOPSIS method and membership function method, Fenzi Zhiwu Yuzhong (Molecular Plant Breeding), 18(7): 2409-2415

Yuan X.Y., Xu S.P., Wang M.F., Lei Z.H., and Cui B., 2019, Cloning of *MhTSJT1* gene from *Phalaenopsis* and its expression under low temperature stress, Jiyinzuxue Yu Yingyong Shengwuxue (Genomics and Applied Biology), 38(2): 707-713

Yu H.X., Zhou Q.M., Sun Y.F., An R.D., Tao L.A., Yang L.H., Dong L.H., Lang R.B., Feng W., Bian X., Zhu J.R., and Jing Y.F., 2015, DTOPSIS evaluation of the nine the national regional sugarcane trail in Yunnan Ruili, Zhongguo Tangliao (Sugar Crops of China), 37(1): 35-37

Zeng S.H., Ren Y., Liu S.J., Guo S.P., Liu L., Xin J.F., and Liu Y.J., 2019, Analysis of characteristic components in mainstream smoke of flue-cured tobacco from main planting areas in Sichuan Province, Yancao Keji (Tobacco Science & Technology), 52(11): 69-77

Zhou Y., Zhou J.H., Deng X.H., and Zhao W.T., 2012, Application of DTOPSIS in comprehensive evaluation of flue-cured tobacco varieties, Zhongguo Yancao Kexue (Chinese Tobacco Science), 33(2): 38-41