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ORIGINAL ARTICLE

Evaluation of the tobacco genotypes by seed productivity

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We presented the results of evaluation of 30 collection varieties of tobacco on podzolized chernozem in the Right-Bank Forest-Steppe of Ukraine. We also determined the essential set of morphological and economically valuable features, which could determine the parents for the hybridization. We performed cluster analysis of tobacco varieties to determine the influence of these features on the seed productivity and separated three clusters, which sufficiently explain 73.32 % of varieties variation. We also made the factor analysis and determined the main features, influenced the seed productivity - inflorescence density, capsules per inflorescence, seeds weight and yield. Three clusters were specified by analysis of these factors with cluster III had highest selection value.
Key words: tobacco, source material, morphological features, economically valuable features, factor analysis, cluster analysis.

Introduction

Tobacco (*Nikotiana tabakum* L., family *Solanaceae*) is a highly profitable industrial crop grown for obtaining of raw material that is used in tobacco products (Goodspeed, 1954; Gebhrdt, 2016). Cigarettes, cigars, and smoking tobacco are made from dried leaves, and food protein is made from green leaves. The characteristic peculiarity of this crop is the content of nicotine alkaloids or nornicotine and anabasine – in some of them. Nicotine is a raw material for producing of insecticides and many chemical preparations (Kovtunyk et al., 2001).

Tobacco areas in Ukraine have decreased by 63 % since 2014 and they are only 0.001 % of the sown area of agricultural crops. Tobacco production fell to a critical level, the industry is declining. Therefore, the production of tobacco products in Ukraine is mostly from imported raw materials. Production of traditional domestic cigarettes was replaced by the cigarettes of the Western marks (Bialkovska, 2013; Morgun et al., 2019). However, cigarette factories in Ukraine may be interested in high-quality and low-toxic tobacco raw materials, which can be obtained by introducing of new high-productive varieties and hybrids of tobacco.

Success in creating of new tobacco varieties and hybrids depends on the availability of genetic resources (Khomutova et al., 2015). However, not all collection samples are suitable for direct use in the selection-and-seed process because of the low productivity, high toxicity, ecological inadaptability, biological incompatibility, etc. (Sarala et al., 2013; Larkyna, 2019). The efficiency of the selection work depends on the correctly chosen source material and the availability of sources of the relevant features that will be involved in hybridization. This will let expand the sown area under tobacco, raise their productivity and increase the production of raw material that meet modern requirements (Ivanitsky et al., 2008; Vinohradov, 2010; Morgun et al., 2019).

The selection process is an important component of tobacco seed production, which combines selection of new varieties, their variety testing, propagation and preservation of seed (biological) properties and yield qualities of seeds (Budarina et al., 2008; Savina et al., 2017; Andrade et al., 2018). The economic value of seed material is connected with the high genetic potential of the varieties by the complex of the features and biological properties that are adapted to different soil and climatic conditions (Yakovuk, 1984; Cherkasov; 2004, Khomutova, 2014). The formation of tobacco seed productivity is a rather complicated process. This is primarily due to the dependence of the development of generative plant organs on the external growing conditions, duration of the vegetative period, as well as the morphological plant characteristics that are inherent in varieties of different tobacco varieties (Boroevich, 1984; Savina & Kovaliuk, 2005; Savina et al., 2007). Each variety is characterized by certain manifestations and relations of the structure components of the seed productivity of the plants, the degree of variability and the presence of the most characteristic of them, which change the least within the variety (Kovaliuk & Sheidyk, 2016). Long-term researches (Sheidyk, 2011; Sheidyk, 2013a, 2013b) proved the need to choose the biotypes that are hereditarily able to be resistant to the environmental factors and have a high genetic potential for the seed yield and quality.

The research aim was to study the peculiarities of the seed productivity formation of the collection tobacco varieties and to specify the sources of valuable features that can be involved in the selection. To establish importance of the individual features and their combination in the formation of the seed productivity and to identify the main of them that directly influence it.

Materials and methods

Research was conducted during 2017–2019 at the Tobacco Research Station of the National Scientific Centre Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine (Uman City, Cherkasy region). This area is within the Right-Bank Forest-Steppe of Ukraine. We choose 30 tobacco varieties with different ecological and geographical origin belonging to seven variety – Krupnolystyi, Burley, Virginia, Trapezond, American, Samsun, and Kerti. The estimated plot area of the collection nursery was 9.7 m^2, repetition – three times. The soil of the collection nursery was podzolized heavy loamy chernozem with a neutral reaction of the soil solution, good physical properties and nutrient regime. The humus content was 3.2–3.4 %.
Weather conditions over the years of the research differed from typical for the region, which had a significant impact on the growth and development of tobacco. The average daily air temperature during the plants vegetation varied from 14.8 to 22.1 °C in 2017, from 17.9 to 22.1 °C in 2018 and from 19.0 to 24.0 °C in 2019, under the average long-term value from 14.6 to 19.0 °C. The average monthly rainfall varied from 41.0 to 59.2 mm in from May to August of 2017, from 18.3 to 92.9 in 2018 and from 34.0 to 69.0 mm in 2019. The weather conditions in 2019 were the hottest and driest for the last 70 years of observations, which caused the shortest vegetation period of tobacco.
Phenological observations, morphological description, biometric measurements and recording of the seed productivity were carried out according to Kosmodemyansky et al. (1974) and Volkodav (2001). The sample size of each variety was 15 plants.
All the varieties were grouped according to the intraspecific tobacco classifier, which is based on a variety type (Psareva, 1969). Evaluation of tobacco samples was performed by plant height, inflorescence height and width, inflorescence density, weight of 1000 seeds, capsules amount per inflorescence, seeds weight per inflorescence and seed yield, and vegetation period duration.
We used Statistica v. 10.0 (STATSOFT Inc., USA) for data processing. We performed factor and cluster analyses to evaluate the genetic diversity of tobacco samples and factors variability.
Factor loads were calculated by principal components and expressed as correlation coefficients (r) with the factor. The $r < 0.5$ were considered as low, $0.7 > r \geq 0.5$ as medium, $0.9 > r \geq 0.7$ – as high, and $r \geq 0.9$ as very high values (Sokal & Rohlf, 1995). We also calculated the characteristic values for each factor, the factors share in total dispersion and the total (cumulative) share of every factor. The selection of optimal factors number was made by "stone rash" criterion (StatSoft Inc., 2013). The cluster analysis was performed for detail evaluation of tobacco samples and their distribution with according to the selection value.

Results

Plant height is an important factor in the formation of tobacco seed productivity. Given this, it is important how the inflorescence is placed – among the leaves or will occupy a third of the plant height without leaves. This is of special significance in the formation of the generative features and the manifestation of the qualitative and quantitative characteristics. The plant height in the collection tobacco samples ranged from 131 to 222 cm (Table 1). We identified 12 tall-growing (from 181 to 222 cm), seven medium-growing (from 165 to 180 cm) and 11 short-growing (from 126 to 158 cm) varieties of tobacco. Varieties belonging to Krupnolystyi and Virginia varieties had the maximum plant height.
During our research, variability in the size of the tobacco inflorescence under the influence of the weather conditions was observed, but the ratio of the inflorescence height to the width remained stable and depended on the sample biotype. Nine varieties of tobacco were characterized by large inflorescences – Ternopilskyi 7, Hostrolyst gigant, Virginia 27, American 201, American 1, American 165, Samsun Krym, Samsun Krasnodar and Samsun Bafra whose height was 30–40 cm and width 25– 7 cm. Inflorescences depending on the flowers density on the branches of the first and second orders were divided into: very loose, non-thick, medium, thick, very thick. Ten varieties of tobacco with very loose inflorescences (Hostrolyst gigant, Burley 7433, Burley White, Spectr, Virginia Joyner, Trapezond Platana, American 1, American 165, Samsun Bafra, Sobolchskyi 33), six varieties with non-thick inflorescences (Hostrolyst Rubin, Burley 38, Trapezond, Trapezond Berehovyi, American 201, Samsun Krym, nine varieties with medium density (Ternopilskyi perspektyvnyi, Hostrolyst Zhovtyi 3, Hostrolyst Yuvileinyi novyi, Bravyi 200, Burley 46, Burley 9, Virginia 202, Virginia Sidlif, Samsun Krasnodar), four varieties with a thick inflorescence (Ternopilskyi 7, Ternopilskyi 14, Krupnolystyi 52, Temp 321) and one variety with very thick inflorescence (Virginia 27) were identified in the collection nursery on this basis.
All studied varieties were early ripening – 50 % of the capsules ripened in 03.09–21.09. Five varieties of tobacco – Ternopilskyi 7, Ternopilskyi 14, Hostrolyst Zhovtyi 3, Hostrolyst Yuvileinyi novyi, and Virginia 27 had large number (121–140 pcs) of the formed capsules in the inflorescence, nine varieties had average number (101–120 pcs) – Ternopilskyi perspektyvnyi, Hostrolyst gigant, Krupnolystyi 52, Bravyi 200, Trapezond Platana, American 1, American 165, Temp 321, and Sobolchskyi 33. Some 16 varieties Hostrolyst Rubin, Burley 46, Burley 9, Burley 38, Burley 7433, Burley White, Spectr, Virginia Joyner, Virginia Sidlif, Virginia 202, Trapezond, Trapezond Berehovyi, American 201, Samsun Krym, Samsun Bafra, and Samsun Krasnodar had small quantity (< 100 pcs).
The seeds weight per inflorescence ranged from 7.7 to 31.8 g. The seed productivity depended on both weather conditions and the genetic potential of the variety. We identified eight highly productive (19–32 g): Ternopilskyi 7, Ternopilskyi 14, Krupnolystyi 52, Hostrolyst Zhovtyi 3, Hostrolyst Yuvileinyi novyi, Samsun Krasnodar, Temp 321, and Virginia 27; 16 average-productive varieties (13–8 g): Ternopilskyi perspectyvnyi, Hostrolyst gigant, Hostrolyst Rubin, Bravyi 200, Burley 9, Burley 38, Burley 46, Virginia Sidlif, Virginia 202, Trapezond, Trapezond Berehovyi, American 201, American 1, American 165, Samsun Krym, and

Samsun Bafra and six low-productivity (7–12 g) tobacco varieties – Burley White, Burley 7433, Spectr, Virginia Joyner, Trapezond Platana, and Sobolchskyi 33.

Table 1. Morphological features and seed productivity of tobacco varieties (average for 2017–2019)

Variety	Variety type	Plant height, cm	• Inflorescence density*	Inflorescence height, cm	Inflorescence width, cm	Capsules amount in the inflorescence, pcs.	Seed weight from inflorescence, g	Weight of 1000 seeds, mg	Seed yield, t/ha	Duration of the vegetation period, days
Ternopilskyi 7 (st)	Krupnolystyi	212	• 7	33	28	146	20.8	73.0	1.00	98
Ternopilskyi 14	Krupnolystyi	204	• 7	23	27	134	20.9	79.5	1.00	98
Ternopilskyi perspektyvnyi	Krupnolystyi	176	• 5	21	23	106	17.7	75.0	0.85	105
Krupnolystyi 52	Krupnolystyi	215	• 7	28	26	120	20.8	70.0	1.00	112
Hostrolyst gigant	Krupnolystyi	193	• 1	37	47	102	13.4	57.0	0.65	105
Hostrolyst Rubin	Krupnolystyi	222	• 3	32	21	76	16.8	70.0	0.81	100
Hostrolyst Zhovtyi 3	Krupnolystyi	215	• 5	26	27	129	19.1	74.0	0.99	116
Hostrolyst Yuvileinyi novyi	Krupnolystyi	187	• 5	22	19	135	19.8	93.0	0.96	100
Bravyi 200	Krupnolystyi	180	• 5	28	38	106	17.2	59.0	0.83	102
Burley 38	Burley	144	• 3	21	22	90	13.2	66.0	0.62	103
Burley 46	Burley	139	• 5	18	21	100	18.0	79.5	0.87	102
Burley 9	Burley	177	• 5	17	23	85	16.5	64.0	0.79	100
Burley 7433	Burley	143	• 1	21	18	96	12.2	92.0	0.59	101
Burley White	Burley	170	• 1	20	16	80	7.7	70.0	0.37	101
Spectr	Burley	194	• 1	20	25	96	12.0	71.0	0.58	103
Virginia 27	Virginia	199	• 9	31	27	126	31.8	76.5	1.53	116
Virginia 202	Virginia	181	• 5	20	16	89	18.3	70.0	0.87	102
Virginia Joyner	Virginia	165	• 1	26	18	73	12.2	90.0	0.59	114
Virginia Sidlif	Virginia	126	• 5	23	17	85	18.0	66.0	0.86	116
Temp 321	Virginia	204	• 7	24	27	115	19.7	74.5	0.94	120
Trapezond	Trapezond	184	• 3	21	26	86	16.2	63.5	0.78	101
Trapezond Berehovyi	Trapezond	153	• 3	20	24	86	15.2	71.0	0.73	116
Trapezond Platana	Trapezond	144	• 1	22	24	101	12.1	89.0	0.58	117
American 201	American	168	• 3	32	44	78	13.4	73.0	0.64	118
American 1	American	141	• 1	37	45	108	14.1	60.0	0.70	115
American 165	American	150	• 1	30	35	117	13.5	62.0	0.64	114
Samsun Krym	Samsun	158	• 3	35	25	82	18.1	89.0	0.87	98
Samsun Krasnodar	Samsun	138	• 5	38	27	91	21.2	80.0	1.02	111
Samsun Bafra	Samsun	131	• 1	40	26	82	16.5	85.0	0.79	98
Sobolchskyi 33	Kerti	173	• 1	21	19	107	12.3	52.0	0.59	105

* Inflorescence density: 1 – very loose, 3 – non-thick, 5 – medium, 7 – thick, 9 – very thick.

The weight of 1000 seeds is important in the seed production of each crop. On average, it was in the range from 52 to 93 g in tobacco varieties during the years of research. There were 20 tobacco varieties with medium seed weight (51–75 mg) – Ternopilskyi 7, Ternopilskyi perspectyvnyi, Hostrolyst gigant, Krupnolystyi 52, Hostrolyst Rubin, Hostrolyst Zhovtyi 3, Bravyi 200, Burley 9, Burley 38, Burley White, Spectr, Virginia Sidlif, Virginia 202, Trapezond, Trapezond Berehovyi, American 201, American 1, American 165, Sobolchskyi 33, Temp 321 and 10 varieties with large seeds (76– 100 mg) – Ternopilskyi 14, Hostrolyst Yuvileinyi novyi, Burley 46, Burley 7433, Virginia 27, Virginia Joyner, Trapezond Platana, Samsun Krym, Samsun Bafra, Samsun Krasnodar. The highest seed yield (more than one t/ha) was in five varieties of tobacco – Ternopilskyi 7, Ternopilskyi 14, Krupnolystyi 52, Virginia 27 and Samsun Krasnodar with the indicators ranging from 1.00 to 1.53 t/ha.

The duration of the vegetation period was directly dependent on variety biological peculiarities and average daily temperature. The vegetation period was 98–116 days during the research, so we considered these varieties as mid-ripening. Two of them – Ternopilskyi 7 and Ternopilskyi 14 had the shortest vegetation period (98 days), six varieties: Krupnolystyi 52, Hostrolyst Zhovtyi 3, Virginia 27, Virginia Joyner, Virginia Sidlif, and Temp 321 had the longest vegetation period (112–120 days).

This analysis was a preliminary estimation of the genotypic potential of tobacco varieties in Right-Bank Forest-Steppe of Ukraine. However, such analysis did not identify the leading (marker) features that affect the seed productivity. Therefore, we performed factor analysis to identify these features. We proved that these main factors explained 73.32 % of general variability (Table 2).

Table 2. Factor analysis statistics

Factors	Characteristic values	General dispersion, %	Cumulant of characteristic values	Cumulant variability, %
1	3.52	39.14	3.52	39.14
2	1.83	20.33	5.35	59.48
3	1.24	13.83	6.59	73.32

Characteristic values of the factors by "Kreiser" and "Stone rash" criterium confirm that 2 and 3 is the optimal number of the factors under a specific space of the registered features. The number of the selected factors satisfies the possibility of estimating the differential difference of the source material by the structure of the main epigenetic systems. It also allows you to manage the appeared variability and heredity and allows you to solve the problem of implementing a specific selection program.
Our results confirmed the optimal detection of the factors structure. They also explain the results of factor analysis by the structure and intensity of appearing the epigenetic systems. We found that the terms of the epigenetic systems can be interpreted according to the leading features of the factors. The first factor can be associated with the manifestation of the epigenetic systems, which has a direct impact on seed productivity (inflorescence density, capsules number per inflorescence, seed weight per inflorescence and seed yield), the second factor – on the inflorescence type (inflorescence height and width) and the third factor – on the formation of new seed material (weight of 1000 seeds).

Table 3. Factor powers

Feature	Factor 1	Factor 2	Factor 3
Plant height, cm	0.57	-0.03	0.59
Inflorescence density	0.91	-0.18	0.04
Inflorescence height, cm	0.17	0.72	-0.41
Inflorescence width, cm	0.07	0.92	0.06
Capsule number per inflorescence, pcs	0.70	0.08	0.26
Seed weight per inflorescence, g	0.94	-0.04	-0.21
Weight of 1000 seeds, mg	0.09	-0.48	-0.68
Seed yield, t/ha	0.95	-0.03	-0.20
Duration of vegetation period, days	0.08	0.40	-0.29
General dispersion	3.52	1.83	1.24
Share of general dispersion	0.39	0.20	0.13

Factor analysis gave the possibility to calculate the factorial values for each form of the source material and to find a virtual matrix of the specificity estimates by the epigenetic variability in terms of the manifestation of the factorial values for each collection tobacco variety. Table 4 shows a matrix of the factorial values for 30 collection samples of tobacco, i.e. a quantitative estimate of the intensity of the factor manifestation which is determined by the relevant mathematical procedures. This makes it possible to conduct an in-depth analysis of the manifestation of a particular epigenetic system in the collection material and to involve it in the implementation of the selection program, as well as to classify it by combination types of the epigenetic systems in the individual samples, i.e. by factors structure. The choice of the optimum methods of the technological decisions of the specific selection problems, in particular selection of the parent systems from the initial selection population, choosing of the pairs for crossing on the basis of the in-depth estimates of the genetic value of the source material as a result of the received information is done. The problem of sufficiency of the available genotypic diversity for realization of the specific program of selection and the problem of expansion of a working collection by the corresponding genetic diversity is solved.
On the basis of factor values, the classification of the collection tobacco samples by the method of the cluster analysis was performed by the epigenotype based on the factorial values and thus the evaluation of the genetic value of the source material was completed. The result of the classification of tobacco varieties by the types of the epigenetic systems combination, i.e. by the structure of the controlled manifestation of the epigenotype in the experiment was presented in fig. 1. It was found that the third cluster including eight varieties of tobacco: Ternopilskyi 7, Ternopilskyi 14, Krupnolystyi 52, Hostrolyst Zhovtyi 3, Hostrolyst Juvileinyi novyi, Bravyi 200, Virginia 27, Temp 321 had a selection value. The most favourable for it is the combination of the epigenetic systems by the state, which determine the implementation of the reproductive ability and the alternativeness by the seed formation.

Table 4. Matrix of factorial values

Variety	Factor 1	Factor 2	Factor 3	Type (cluster)
Ternopilskyi 7	1.58	0.17	0.85	3
Ternopilskyi 14	1.35	-0.66	0.74	3
Ternopilskyi perspektyvnyi	0.29	-0.65	0.25	2
Krupnolystyi 52	1.33	0.18	0.56	3
Hostrolyst gigant	-0.46	2.41	1.04	1
Hostrolyst Rubin	-0.02	-0.13	0.60	2
Hostrolyst Zhovtyi 3	1.10	0.27	0.48	3
Hostrolyst Yuvileinyi novyi	0.94	-1.39	-0.24	3
Bravyi 200	0.30	0.99	1.01	3
Burley 38	-0.87	-0.45	0.38	2
Burley 46	0.03	-1.16	-0.46	2
Burley 9	-0.14	-0.80	1.06	2
Burley 7433	-1.08	-1.29	-0.82	2
Burley	-1.70	-0.93	0.96	2
Spectr	-0.84	-0.34	1.15	2
Virginia 27	2.90	0.21	-1.05	3
Virginia 202	0.16	-1.15	0.47	2
Virginia Joyner	-1.11	-0.62	-1.26	1
Virginia Sidlif	-0.17	-0.40	-0.87	1
Temp 321	1.08	0.14	0.13	3
Trapezond	-0.29	-0.24	0.99	2
Trapezond Berehovyi	-0.54	-0.15	-0.28	2
Trapezond Platana	-0.97	-0.30	-1.11	1
American 201	-0.60	1.78	-0.61	1
American 1	-0.56	2.52	-0.33	1
American 165	-0.60	1.44	0.20	1
Samsun Krym	-0.10	-0.23	-1.54	1
Samsun Krasnodar	0.51	0.58	-2.09	1
Samsun Bafra	-0.64	0.32	-1.95	1
Sobolchskyi 33	-0.87	-0.10	1.72	2

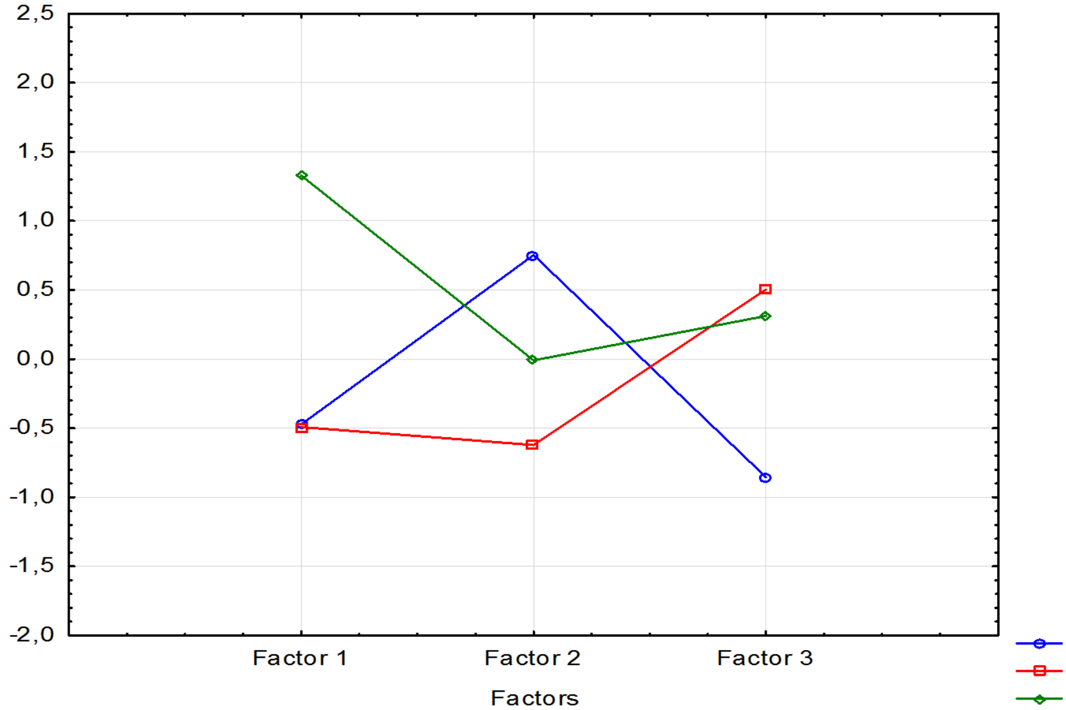

Fig 1. Cluster analysis factor values among tobacco varieties. Factor 1 – seed yield, Factor 2 – inflorescence size, Factor 3 – weight of 1000 seeds.

Conclusions

We determined the specific tobacoo varieties with valuable trade features, namely 12 varieites with desirable plant height, nine varieites with inflorescence size (length and width), five varieites with high capsule number per inflorescence, 8 varieites with large seed weight per inflorescence, 20 varieties with desirable weight of 1000 seeds, five with high seed yield and two with proper duration of vegetation period. The collection samples of tobacco were systematized and the leading features influencing the formation of the seed productivity were determined with the help of the factor and cluster analyses. The obtained results could be used in crossing and selection of valuable genotypes.

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