AGRICULTURAL BIOLOGY,
2020, V. 55, № 3, pp. 564-572
(SEL'SKOKHOZYAISTVENNAYA BIOLOGIYA)

ISSN 2412-0324 (English ed. Online)
ISSN 0131-6397 (Russian ed. Print)
ISSN 2313-4836 (Russian ed. Online)

UDC 633.85:631.526.32:574.24

doi: 10.15389/agrobiology.2020.3.564eng
doi: 10.15389/agrobiology.2020.3.564rus

EVALUATION OF WINTER CAMELINA (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) CULTIVARS FOR ENVIRONMENTAL ADAPTABILITY

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The authors declare no conflict of interests
Received August 18, 2019

Abstract

Winter camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) is a promising oilseed crop that enjoys great popularity in the world because of high oil content and a wide range of uses. From the environmental point of view, winter camelina possesses phenotypic plasticity and seems to be particularly adapted to a wide range of soil and climatic conditions. Camelina is a cold-resistant and drought-tolerant plant. Spread of winter camelina cultivation and its productivity improvement depends on the genetic diversity of cultivars adapted to the conditions of the region of its cultivation, as well as on the genotype-environment interaction. In the presented work, it was first established that in the conditions of the Middle Volga and Steppe Crimea, winter camelina specimens are adaptable, stable and able to produce high yield of good quality. This allows us to involve these forms in breeding new varieties adapted for cultivation in both regions. The aim of the work is to evaluate the cultivars of winter camelina for environmental adaptability and stability in two contrasting agroecological regions, the Middle Volga Region (Penza Agricultural Research Institute) and the steppe zone of the Crimea (Research Institute of Agriculture of Crimea) in 2015-2017. Varieties of *Camelina sylvestris* of various ecogeographical origins were investigated. Cultivar Penzyak (Penza Agricultural Research Institute) served as a standard. This cultivar has been cultivated in the Crimea on an industrial scale since 2015. Winter hardiness of the studied cultivars in the fields of Penza was high and ranged between 89.5 % to 96.7 %, in the Crimean Peninsula territory it was 92.3-96.9 %. Various hardiness groups were identified: samples with high cold tolerance (more than 98 %), samples with the middle level of winter hardiness (90-95 %), and samples with low winter-tolerance (less than 90 %). Winter hardiness of the same samples varied within the range of 92.3-96.9 % under the Crimean environment. The highest level of winter hardiness was noted for the cultivar Baron and individual selection line 4156, which exceeded standard cultivar Penzyak by 0.8-1.0 %, respectively. The productivity of varieties in the Crimea was 1.64-1.83 t/ha. Seed oil content varied from 35.61 to 43.90 %. The highest content of fat in seeds was noted in varieties Baron and Kozyr (43.90 and 43.60 %). Realization of yield potential of winter camelina cultivars and samples in the forest-steppe zone of the Middle Volga and steppe zone of the Crimea was relatively high, 70.9-88.9% and 71.1-86.3%, respectively. The highest level of yield realization was identified for the cultivar Dikiy (86.3 % and 88.9 %). Two samples (Dikiy and individual selection line 3290) were the most effective in terms of productivity. Their productivity was 1.83-1.97 when cultivated in Penza Agricultural Research Institute, and 1.73-1.85 t/ha in Research Institute of Agriculture of Crimea. On average, cultivar Dikiy (88.9 g/m^2) and individual selection line 3290 (85.4 g/m^2) showed the highest level of adaptability to the conditions of both territories. The lowest adaptability criterion was identified for the individual selection line 4172 from Sverdlovsk and individual selection line 4175 from Czechoslovakia, the fitness coefficients amounted 56.3 and 59.6 g/m^2, respectively. High adaptability of the samples (b_i = 0.98-0.99 for Dikiy and bi = 0.96-0.95 for individual selection line 3290) allows their cultivation both in the Middle Volga and in Steppe Crimea. Low adaptability was noted for the individual selection line 2219 (b_i = 0.89) in the Penza region; in the Crimea, for the aforementioned individual selection line b_i was 1.15.

Keywords: winter camelina, productivity, cultivation, region, Middle Volga, Crimea, oil content

Negative environmental factors, including temperature fluctuations and excessive or insufficient moisture, adversely affect plants during their growth and development. Each plant has a genotypically determined ability to adapt to changing environmental conditions. According to Zhuchenko [1], plant adaptability and resistance to unfavorable factors are the fundamental criteria in adaptive breeding. At the same time, the adaptability of new varieties to specific soil and climatic conditions characterizes their agroecological targeting [1].

Winter camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) is an oilseed crop that is becoming more and more popular due to its high oil content and multi-purpose use [2, 3]. The potential yield of camelina seeds is over 2.0 t/ha, and the oil content is over 40% [4, 5]. Camelina oil is an edible oil used directly in food due to good taste, but it is also a raw material for production of drying oil, synthetic lipids, green soap and other technical products [6-8], and also is used in cosmetics, aromatherapy, and medicine [9, 10]. In addition, the camelina is promising source for production of biodiesel and bio kerosene which show excellent physical and chemical characteristics and operational parameters [10-12].

The uniqueness of winter camelina lies in its low demands on growing conditions due to its high adaptability [14-16]. From an ecological point of view, winter camelina is a fairly plastic plant that easily adapts to various soil and climatic conditions [17, 18]. The distinctive features of camelina are high winter hardiness [19], early maturation and drought resistance [20, 21].

According to the FAO (Food and Agriculture Organization) reports, winter camelina is currently cultivated in a number of regions of the Russian Federation on an area of 142 thousand hectares [22]. However, for Crimea, this is a new crop the study of which began in 2015.

An increase in the acreage of winter camelina crops and an increase in its productivity depend on the genetic diversity of varieties and specimens adapted to local conditions, as well as on the genotype—environment interaction [23, 24]. Modern methods of plant breeding, including for oilseeds, aim not only to increase seed productivity and quality, but also to improve potential adaptive capabilities of the genotype when exposed to biotic and abiotic environmental factors [25, 26]. Estimates of adaptability and stability are mandatory in characterization of new highly productive varieties of winter camelina intended for practical use.

This work, summarizing results of long-term research, shows that the varieties of winter camelina studied for the first time in the conditions of the Middle Volga region and the steppe Crimea, are well-adaptable, stable and capable of high yielding and producing quality seeds of high quality. Thence, these varieties can be involved in breeding to derive varieties adapted to cultivation in both regions.

Our objective was to evaluate the ecological adaptability and stability of winter camelina varieties in contrasting agroecological conditions.

Materials and methods. Winter camelina varieties Penzyak, Kozyr, Baron and breeding lines Dikii, i.o.-4172, i.o.-1357, i.o.-2219, i.o.-4155, i.o.-4164, i.o.-4156, i.o.-4175, i.o.-3290, i.o.-4165 of various ecological and geographical origin were used in experiments carried out in 2015-2017 in two agroecological regions with contrasting climatic conditions, the Middle Volga (Penza Research Institute of Agriculture, settlement Lunino, Penza Province) and the steppe Crimea (Research Institute of Agriculture of Crimea, Klepinino village, Krasnogvardeiskii District). The Penzyak variety originated by the Penza Research Institute of

Agriculture served as the standard.

The soil of the first experimental site (the Penza Research Institute of Agriculture) is leached chernozem with a humus content in the arable layer of 6.4% and 81.3, 136.7 and 164.9 mg/kg nitrogen, phosphorus and potassium, respectively; pH 5.5. The soil of the second experimental site (the Research Institute of Agriculture of Crimea) is southern low-humus chernozem with 2.4-2.6% humus and 2.2, 4.5 and 39.0 mg/kg nitrogen, phosphorus and potassium, respectively; pH 7.3

In 2009, in the Penza Research Institute of Agriculture (PRIA), the initial breeding material was obtained by individual selection method using accessions of the PRIA collection of camelina varieties. In 2014, the resulting lines were subjected to environmental tests at the Research Institute of Agriculture of Crimea.

The cultivation of camelina in the crop rotation, field experiment design, observations and measurements were carried out as per the recommendations for oilseeds [27]. Sowing was carried out at the optimal time for a particular region in an ordinary way with 15 cm row spacing and a seeding rate of 8.0 million/ha Winter hardiness was assessed by the data of autumn and spring estimates of the crop states in each repetition in both zones. The yield was measured in 1 m^2 plots.

Statistical processing was performed according to Dospekhov [28] using Microsoft Excel 2010 and a Statistica 8 software package (StatSoft, Inc., USA). The mean values (M*)* and their standard errors (±SEM) were calculated. The significance of differences between the options was assessed by the methods of parametric statistics (Student's *t*-test). Ecological stability and adaptability (b_i) were determined as described by Kilchevsky and Khotyleva [29] based on the regression coefficient. Yield potential realization was expressed as the percentage ratio of the maximum yield to the average yield according to Nettevich [30]. The plant fitness criterion (K_0) was determined according to the method described by Belenkevich [31] which is based on the calculation of averaged parameters of plant productivity and its structural components.

Results. The climate of the Middle Volga region is temperate continental with annual precipitation from 350 to 750 mm. During the years of our survey, the climatic conditions differed in moisture conditions: growing season of 2016 was characterized as arid (the hydrothermal coefficient HTC 0.74), while 2015 was highly humidified (HTC 1.37). The year 2017 turned out to be optimal with regard to water supply (HTC 1.10).

The second experimental site (the Research Institute of Agriculture of Crimea) belongs to the zone of the steppe Crimea, the climate is characterized as continental, the amount of precipitation per year averages 428 mm. On average for 2015-2017, from 334.7 to 606.9 mm precipitation fell during the growing season of winter camelina. The driest year was 2017 (HTC 0.61), 2016 was characterized as insufficiently humidified (HTC 0.82), and the optimal water supply was in 2015 (HTC 1.11).

Winter hardiness is an important biological trait that determines the ability of plants to withstand low temperatures and other stressors in winter and early spring. Wither camelina differs from other winter cabbage crops (for example, rapeseed and winter rocket) in high frost and winter resistance [18, 20]. Under the conditions of Penza region, winter hardiness of the camelina varieties ranged from 89.5 to 96.7%. There were samples of a high (95.3-96.7% for Kozyr, Baron, i.o.-4164, i.o.-3290, and i.o.-2219), moderate (93.2-94.8% for Penzyak, Dikii, i.o.-4165, i.o.-1357, i.o.-4175) and low (89.5-89.9% for i.o.-4172, i.o.-4155, and i.o.-4156) winter hardiness (Table 1).

1. Winter hardiness of camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) varieties and breeding lines cultivated in different regions (M±SEM, 2015-2017)

Variety, line	Origin	Region of cultivation	
		the Middle Volga (settlement Lunino, Penza Province)	the steppe Crimea (Klepinino village, Krasnogvardeiskii District
Panzyak (st)	Penza	94.8±0.98	95.9±0.33
Kozyr	Penza	95.3±0.98	95.6±0.33
Baron	Penza	96.5±0.98	96.7±0.33
Dikii	Astrakhan	93.9±0.98	93.3±0.33
i.o.-4172	Sverdlovsk	89.9±0.98	93.9±0.33
i.o.-1357	France	94.2±0.98	92.3±0.33
i.o.-2219	Ukraine	95.9±0.98	93.1±0.33
i.o.-4155	Dagestan	89.7±0.98	92.9±0.33
i.o.-4164	Sweden	96.3±0.98	95.7±0.33
i.o.-4156	Mari El Republic	89.5±0.98	96.9±0.33
i.o.-4175	Czechoslovakia	93.9±0.98	96.3±0.33
i.o.-3290	Altai	96.7±0.98	95.0±0.33
i.o.-4165	Germany	93.2±0.98	94.2±0.33
LSD_{05}		1.08	0.99

N o t e. Panzyak variety is the standard (st), p = 0.05.

In Crimea, the resistance of camelina cultivars to overwintering conditions was quite high (92.3-96.9%). The highest value was observed in the Baron variety and i.o.-4156 breeding line, which exceeded the standard variety by 0.8 and 1.0%, respectively.

The yield of the studied varieties and lines varied depending on the region of cultivation. However, the Dikii and i.o.-3290 lines were much more effective than the control: their productivity in the Middle Volga region was 1.85 and 1.97 t/ha, respectively, in the Crimea 1.73 and 1.83 t/ha, respectively (Table 2), which indicates the highest adaptability, plasticity and stability of these varieties in stressful conditions. In addition, in the conditions of the steppe Crimea, the line i.o.-1357 (France) stood out in terms of yield, exceeding the control by 0.10 t/ha.

2. Total seed yield and oil yield of camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) varieties and breeding lines cultivated in different regions (M±SEM, 2015-2017)

Variety, line	Origin	Middle Volga (settlement Lunino, Penza Province)		Steppe Crimea (Klepinino village, Krasnogvardeiskii District)	
		yield, t/ha	oil content, %	yield, t/ha	oil content, %
Panzyak (st)	Penza	1.65±0.08	38.74±0.98	1.64±0.03	41.25±1.08
Kozyr	Penza	1.79±0.07	39.66±0.98	1.66±0.02	43.50±1.08
Baron	Penza	1.86±0.05	40.46±0.88	1.59±0.02	43.90±1.08
Dikii	Astrakhan	1.97±0.08	40.19±1.02	1.83±0.02	38.19±1.10
i.o.-4172	Sverdlovsk	1.57±0.07	38.53±1.01	1.54±0.03	36.71±1.08
i.o.-1357	France	1.69±0.08	38.69±0.98	1.74±0.03	38.03±1.09
i.o.-2219	Ukraine	1.81±0.09	37.42±0.88	1.57±0.03	35.61±0.98
i.o.-4155	Dagestan	1.76±0.07	38.41±0.88	1.66±0.02	37.79±0.99
i.o.-4164	Sweden	1.64±0.08	37.96±0.98	1.67±0.02	38.70±1.01
i.o.-4156	Mari El Republic	1.72±0.09	37.38±0.98	1.69±0.02	38.37±0.99
i.o.-4175	Czechoslovakia	1.61±0.09	37.79±0.98	1.56±0.03	36.95±1.08
i.o.-3290	Altai	1.85±0.09	39.58±0.88	1.73±0.02	38.29±1.08
i.o.-4165	Germany	1.72±0.08	38.83±0.88	1.67±0.02	38.27±1.08
LSD_{05}		0.12	1.03	0.04	1.12

N o t e. Panzyak variety is the standard (st), p = 0.05.

The seed oil content varied from 35.61 to 43.90%. The oiliest varieties were Baron and Kozyr, 43.90 and 43.60%, respectively. It can be said that they showed ecological plasticity when tested in various agroclimatic conditions. In the Penza region, it is worth noting i.o.-2219 (Ukraine), the yield of which was 1.81 t/ha, exceeding the standard variety Penzyak by 0.16 t/ha.

The realization of the productivity potential of varieties and lines of winter camelina both in the forest-steppe zone of the Middle Volga and in the steppe zone of the Crimea was generally comparable and reached the values of 70.9-88.9 and 71.1-86.3%, respectively. The lines i.o.-3290 and Dikii used their capabilities most fully, 82.5-84.9 and 86.3-88.9%, respectively, which can be explained by their greater ability to withstand the action of abiotic stresses (Fig. 1).

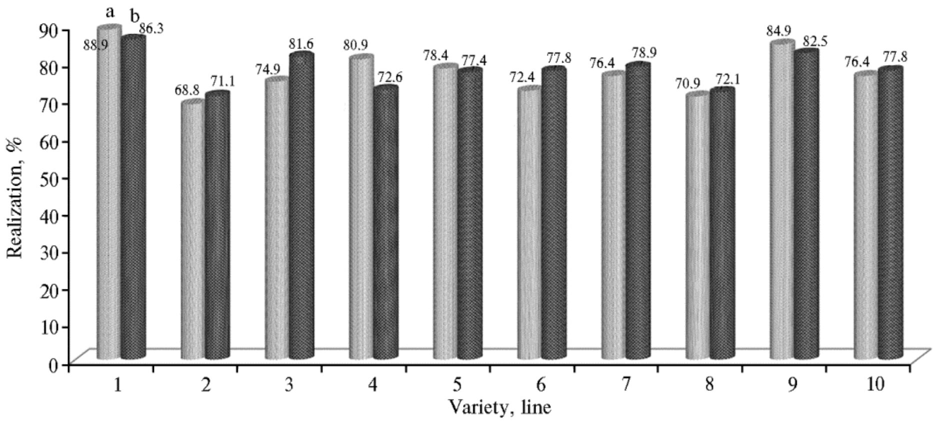

FIg. 1. Realization of potential productivity of camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) varieties and breeding lines cultivated in the Middle Volga (settlement Lunino, Penza Province) (a) **and the Steppe Crimea** (Klepinino village, Krasnogvardeiskii District) (b) **conditions:** 1 — Dikii, 2 — i.o.-4172, 3 — i.o.-1357, 4 — i.o.-2219, 5 — i.o.-4155, 6 — i.o.-4164, 7 — i.o.-4156, 8 — i.o.-4175, 9 — i.o.-3290, 10 — i.o.-4165 (2015-2017).

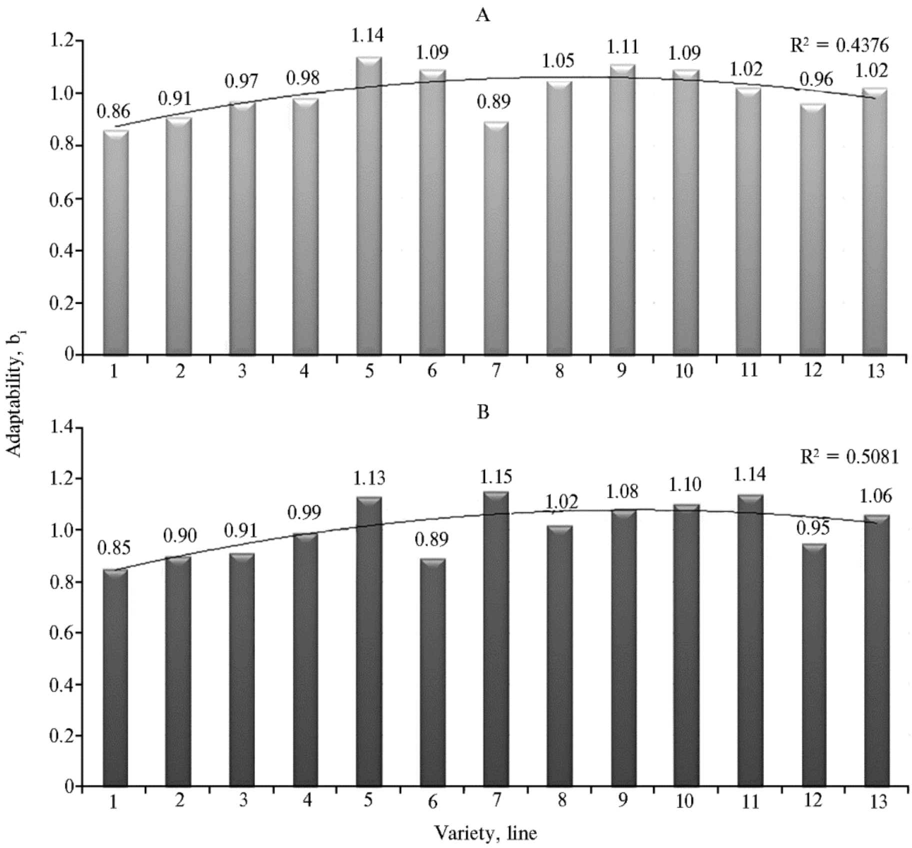

Fig. 2. Adaptability of camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) varieties and breeding lines cultivated in the Middle Volga (settlement Lunino, Penza Province) (A) **and the Steppe Crimea** (Klepinino village, Krasnogvardeiskii District) (B) **conditions:** 1 — variety Penzyk (standard, st), 2 — variety Kozyr, 3 — variety Baron, 4 — Dikii, 5 — i.o.-4172, 6 — i.o.-1357, 74 — i.o.-2219, 8 — i.o.-4155, 9 — i.o.-4164, 10 — i.o.-4156, 11 — i.o.-4175, 12 — i.o.-3290, 13 — i.o.-4165 (2015-2017).

The most stable and plastic both under the conditions of the Middle Volga region and the steppe Crimea were the breeding lines Dikii (b_i = 0.98-0.99) and i.o.-3290 (b_i = 0.96-0.95), which turned out to be more adapted to various, including unfavorable, growing conditions (Fig. 2). Lines with the regression coefficient $b_i > 1.0$ are of the intensive type, respond well to the improvement of agrotechnological conditions, but more often decrease their productivity under stressful agroclimatic conditions [22, 23].

The productivity of a crop depends on the components of the yield structure, the contribution of which to the final yield is determined by the influence of genotype and environmental factors [24] and is assessed by the criterion of adaptability (K_0) to the cultivation conditions [31]. In our experiments, for both regions on average, in the lines i.o.-3290 (85.4 g/m^2) and Dikii (88.9 g/m^2) the fitness criterion values were the highest (Table 3). Low K_0 values were noted in the lines i.o.-4172 (Sverdlovsk) and i.o.-4175 (Czechoslovakia), 56.3 and 59.6 g/m^2, respectively. An increase or decrease in the K_0 values in the camelina samples occurred as a result of changes in the ratio of the contributions of the main components to the final seed yield.

All breeding lines had positive K_0 values, which was mainly due to compensatory effects of an increase in the number of pods per plant, the number of seeds per pod, and the 1000-seed weight. Upon a negative value of one of the parameters, the positive criteria were overlapped by positive effects on other components of the seed yield. This explains different response of varieties to climatic factors during the growing season, as well as plant adaptability and fitness to the regions of cultivation.

3. Plant fitness criterion (K_0) **of camelina (*Camelina sylvestris* Waller ssp. *pilosa* Zing.) varieties and breeding lines cultivated in different regions** (2015-2017-year average)

Variety, line	Total fitness criterion, g/m^2	Contribution of yield structure component to K_0, %		
		pod number	seeds per pod	1000-seed weigh, g
Panzyak (st)	83.7	78.6	28.8	14.2
Kozyr	84.1	81.2	33.1	15.2
Baron	84.9	75.9	26.3	17.2
Dikii	88.9	119.6	–30.7	35.1
i.o.-4172	56.3	46.5	–21.6	32.8
i.o.-1357	79.5	79.5	96.8	–47.3
i.o.-2219	72.3	102.0	50.8	17.2
i.o.-4155	74.6	85.6	–43.1	61.8
i.o.-4164	69.8	78.6	55.6	–40.9
i.o.-4156	75.1	77.5	–27.7	50.2
i.o.-4175	59.6	51.3	–28.3	–33.9
i.o.-3290	85.4	75.9	29.4	45.3
i.o.-4165	71.9	66.3	50.3	–64.0

N o t e. Panzyak variety is the standard (st).

Currently, due to changes of climatic conditions, the assessment of the crop adaptability and stability is one of the most important in breeding. Among the first publications on assessing the stability and adaptability of winter camelina varieties is the work of Prakhova et al. [20], where the varieties Penzyak, Kozyr, Baron and Peredovik were tested in various agroecological conditions of Volgograd, Krasnodar, the Republic of Crimea, and the Penza region. We could not find other similar publications for winter camelina. However, a large number of similar works are known for other crops (also with regard to ecologically sustainable agriculture), including wheat [32], barley [33], corn [34], flax [24], rapeseed [18].

Korolev et al. [24] reported about the possibility of identifying adaptive and stable forms in fiber flax in the conditions of Belarus. Diederichsen et al. [35] carried out such studies at the All-Russian Research Institute of Flax (Torzhok). Based on the analysis of the works of other authors and the assessment of the breeding material of winter camelina, we have identified a number of promising varieties that exceed the existing varieties in terms of adaptability and stability and can produce stable yields upon a deterioration in temperature conditions and water supply.

Thus, as a result of the agroecological assessment of winter camelina for the main parameters of productivity, stability and ecological plasticity in two contrasting agroecological regions, we identified varieties characterized by high productivity and resistance to various cultivation conditions. The most stable and plastic breeding lines are Dikii (b_i = 0.98-0.99) and i.o.-3290 (b_i = 0.96-0.95), which significantly exceeded the Penzyak variety in both regions. These samples have a high selection value and can be used to derive varieties with high stable productivity and adaptability to the contrasting conditions of the regions. Among the studied samples, i.o.-4155, i.o.-4156 and i.o.-4165 had low but stable yields over the years (1.66-1.76 t/ha) and b_i = 1.02-1.10, which shows their responsiveness to changes in cultivation conditions

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