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Breeding of spring turnip rape, *Brassica rapa L. var. subsp.campestris* (L.) *A.R Clapham* at All-Russian Research Institute of Oil Crops

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ABSTRACT

Turnip rape, *Brassica rapa L. var. sabsp. Campestris* (L.) *A.R.Clapham* belongs to the large cabbage family (*Brassicacea*). Spring turnip rape among other oilseeds of the *Brassicacea* family occupies an important place and can be highly productive in the Northern regions of the European part, in the arid zones of the Lower Volga region, in the northern forest-steppe and subtaiga regions of Western and Eastern Siberia, where the longer growing season sometimes hinders rapeseed to achieve its full potential. Spring turnip rape ripens 13-15 days earlier than rapeseed; it is less heat- and drought-sensitive. However, interest in industrial cultivation of spring turnip rape appeared in the 70s of the last century after the creation of non-erucic and low-glucosinolate varieties, with the oil equivalent to olive oil in its fatty acid composition. Spring turnip rape has been bred at V.S. Pustovoyt All-Russian Research Institute of Oils Crops (VNIIMK) since 1982. The yellow-seeded varieties, Vostochnaya, Yantarnaya, and Zolotistaya, were created. The objective of this research was to find a new promising breeding material for creating varieties of 000-type spring turnip rape from heterogeneous populations of the available VNIIMK varieties. To obtain a new source material, we used the pedigree method, followed by an assessment of the progeny of elite plants isolated from Yantarnaya and Zolotistaya. The result of our six-year efforts was four new promising samples No. 815, 844, 816, and 820, which exceed the standard variety, Zolotistaya, in seed yield by 10-14%. The oil content of seeds of the isolated samples varied from 47.8 to 48.6%, and exceeded the standard variety by 0.3–0.7% in three of them. Promising cultivars either had the same or lower weight of 1000 seeds (2.4-3.0 g), in comparison with Zolotistaya. All selected samples of turnip rape were characterized by a low glucosinolate content in seeds – 13.5–14.5 μmol g^{-1}, and the fatty acid composition corresponded to the requirements for high-quality salad oils with erucic acid levels of 0.04–0.20% and a high content of oleic acid – 65.8–67.4%. After additional assessment, the best variety will be submitted for the State test.

Keywords: Spring turnip rape, Breeding, Seed yield, Oil content, Glucosinolates.

Article type: Research Article.

INTRODUCTION

Turnip rape, *Brassica rapa L. var. sabsp. Campestris* (L.) *A.R.Clapham* belongs to the large cabbage family (Brassicacea) and is a long day crop. There are winter and spring forms of turnip rape. It is preferred and mainly grown in Sweden, Finland, India, parts of Canada and northwest China. Turnip rape also has commercial value in Canada and Australia (Dospekhov 1973; Buiankin& Fedorova 2007). In Finland, spring turnip rape is the dominant oilseed crop due to its lower production risks compared to spring rapeseed. The growing area of spring turnip rape in this country is 100 thousand hectares, which is 93% of the total area of all oilseed crops (Downey & Klassen 1974; Jönsson 1978; Daun & DeClercq 1986). In India, turnip rape is an important source of feed

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additives for dairy cows; the plant can accumulate heavy metals and grows on soils with high concentrations of As, Cr, and Cu [6]. In China, Thailand, and Japan, *Brasica rapa* is represented by various phenotypes with a wide morphological diversity, used both as sources of oil and as vegetable crops [7]. Turnip rape, as well as rapeseed (*Brassica napus* L.) are noted in the Brockhaus and Efron Encyclopedic Dictionary (volume XXVI, 1899). The oils obtained from the non-drying seeds of these crops have long been used in tanneries, cloth factories, soap making, lighting, and also food. Old-timers of the Kuban described "suripa" oil as pleasant to taste and usually used it with vegetable salads. At the end of the XIX century, turnip rape and rapeseed-growing area reached 350 thousand hectares. Turnip rape was grown in the central and eastern provinces of Russia. Then the areas under these crops began to decrease, as the world demand for Russian grain increased. By early 50s of the XX century, sunflower production began to develop intensively in our country, which turned out to be difficult for other oilseeds to compete with. Turnip rape and rapeseed got their "second wind" in the 70s of the last century after the creation of new non-erucic and low-glucosinolate cultivars (00 type) first in Canada and then in Western Europe (Bhargava *et al.* 1996; Lukomets 2010; Nonda, R, Kuznetsova & Poliakova 2019). The oil of 00-type varieties, generally named "canola", has fatty acid composition equal to olive oil. In 1982, VNIIMK and its Siberian experimental station started a planned breeding to create 00 and 000 type rapeseed and turnip rape varieties (Lukomets 2010).

Spring turnip rape occupies an important place among other oilseeds of the *Brassicacea* family. Despite the lower biological productivity by 15–20% than in spring rapeseed, and can be highly productive in the Northern regions of the European part, the longer growing season sometimes hinders rape to achieve its full potential in the arid zones of the Lower Volga region, in the northern forest-steppe and subtaiga regions of Western and Eastern Siberia. Turnip rape ripens 13-15 days earlier than rapeseed; it is less heat- and drought-sensitive. From sowing to harvesting, spring rapeseed requires 1650-1750 °C, while turnip rape needs 1250-1350 °C. Favorable hydrothermal conditions ensure the same level of the yield of turnip rape and rapeseed (1.5-2.0 ton ha^{-1}). Thus, in the Non-Chernozem Zone of Russia, the yellow-seed varieties of Svetlana (All-Russian Research Institute of Feed) and Zolotistaya (VNIIMK) showed a seed yield of 2.1 ton ha^{-1} on average for 3 years (2004-2006; Peltonen-Sainio *et al.* 2007. In Western Siberia, according to the Siberian experimental station of VNIIMK, varieties of spring rape show a fairly stable yield - from 1.99 to 2.26 ton ha^{-1} in 2014 (Peltonen-Sainio, *et al.* 2009a) and on average from 1.58 to 2.28 ton ha^{-1} in 2015-2018. Testing of Yantarnaya spring turnip rape (VNIIMK) at Lower Volga Research Institute of Agriculture and Volga Region Breeding and Experimental Station showed the seed yield from 0.8 to 1.0 ton ha^{-1} in a very drought season of 2002. In more favorable conditions in 2003 the seed yield was 2.0 ton ha^{-1}, and in a fallow field, the seed yield was 2.8 ton ha^{-1} (Peltonen-Sainio, *et al.* 2009b). Both foreign and domestic experts of the oil and fat industry say that oil of modern varieties of turnip rape and rape, containing 65-68% oleic acid (omega 9), 19-20% linoleic acid (omega 6) and 7-8% linolenic acid (omega 3) is a high quality salad oil.

Virgino cold-pressed rapeseed oil (Kankaisten Öljykasvit Oy, Finnish company) is one of the most popular oils in Finland. Suomi call it "Northern olive". This oil is sold in all Finnish retail chains, including such as Stockman, Prisma, City-Market. Specialists of Sarepta plant in the Volgograd region note a pleasant soft taste and aroma, and a high shelf life of rapeseed oil (12 months). This plant produces Olivia oil based on turnip rape and camelina oils, which is popular among the residents of the Volgograd region (Peltonen-Sainio, *et al.* 2009b) One of the advantages of modern varieties of spring turnip rape is the yellow color of the seeds (000 type). Yellow-seed cabbage oil crops (*Brassica juncea* L., *Brassica rapa* L., *Brassica napus* L.) are known for a higher oil content in comparison with black seeds, due to a thinner seed coat (Rakow 2004). When processed, yellow-seed cabbage oil crops have higher oil yield, lower costs of cleaning and bleaching, and higher feed value of the cake (meal). Based on the experiments on the use of turnip rape seeds (Yantarnaya, 000 type) in feeding broiler chickens, conducted at North Caucasus Research Institute of Animal Husbandry (Krasnodar), the inclusion of 10-15% of turnip rape seeds in compound feed has been reported to increase the average daily weight gain in the experimental group by 3.9% compared with the control. Feed-gain ratio decreased in the experimental group by 14.7% (Shpota *et al.* 1986). In foreign countries, the inclusion of cake (meal) with a low content of glucosinolates in the diet of animals is a key factor in the intensification of animal husbandry, especially poultry and pig breeding. Experts have found a higher energy value of yellow-seed turnip rape cake compared to grey-seed turnip rape. The former contains 35-40% protein, which makes it close to soybean meal, and surpasses it in the content of methionine and tryptophan. Thus, growing spring turnip rape in the regions less suitable for other oilseeds can become a reserve for replenishing the resources of high-quality edible vegetable oil and fodder protein. The objective is to find a new promising breeding material for creating 000-type varieties of spring turnip rape.

MATERIALS AND METHODS

The studies were conducted at the central experimental at V.S. Pustovoyt All-Russian Scientific Research Institute of Oil Crops in 2015-2020, in the central zone of the Krasnodar Territory. The original material was Yantarnaya and Zolotistaya yellow-seeded varieties (000 type) bred by intraspecific hybridization followed by individual family selection from hybrid populations. To obtain a new original material, the pedigree method was used, followed by an assessment of the offspring. Field experiments were launched according to the VNIIMK adopted methods (Sinam *et al.* 2015) and the state agricultural crop variety testing methodology (Volovik *et al.* 2012). Seed were sown with Wintersteiger seeder. The plot area of the breeding nursery was 7.5 m^2, in triplicate, and the plot area of the competitive testing was 12 m^2, in quadruplicate. Biochemical analyzes of seeds were carried out in the laboratory of biochemistry on NMR analyzer and Chromatek-Kristall 5000 gas chromatograph. The content of glucosinolates in seeds was determined by the palladium test. Statistical processing was carried out using the Excel one-way analysis algorithm and an additional calculation of the least significant difference (LSD) as presented by Dospekhov (1973).

RESULTS AND DISCUSSION

A comparative assessment of the main economic characteristics of spring rapeseed and turnip rape used the average data of the competitive testing of these crops (33 samples in each nursery). Analysis of the 5-year average data showed turnip rape to be inferior to rapeseed in seed yield by 24%, in oil yield by 19%, but have shorter growing season (by 14 days) and a lower content of glucosinolates in seeds (Table 1).

Table 1. Economic characteristics of spring rape and turnip rape in the central zone of Krasnodar Territory for 2016-2020.

Crop	Growing period, days	Seed yield		Seed oil content	Oil yield		Glucosinolate content
		ton ha^{-1}	% to rape	%	ton ha^{-1}	% to rape	µmol L^{-1}
Turnip rape	75	1.30	76	46.8	0.55	81	13.1
Rapeseed	89	1.70		44.6	0.68		16.1

The yield of turnip rape was practically the same with rapeseed in some years characterized by a catastrophic spread of cabbage moth (2018 and 2019 in our studies; Fig. 1).

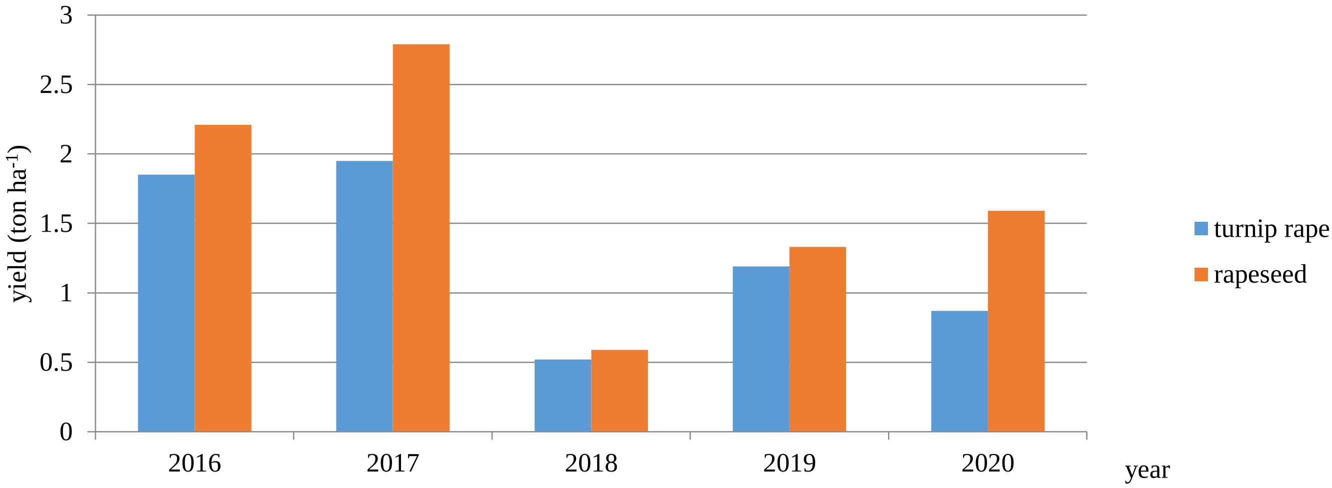

Fig. 1 Seed yielding capacity of spring rape and turnip rape, based on the conditions of the year.

In 2020, seed yielding capacity of both crops, especially turnip rape, was affected by frequent rainstorms during the harvesting period. The oil content of turnip rape seeds in all the studied years was higher than that of rapeseed by 0.6–2.7% (Fig. 2).

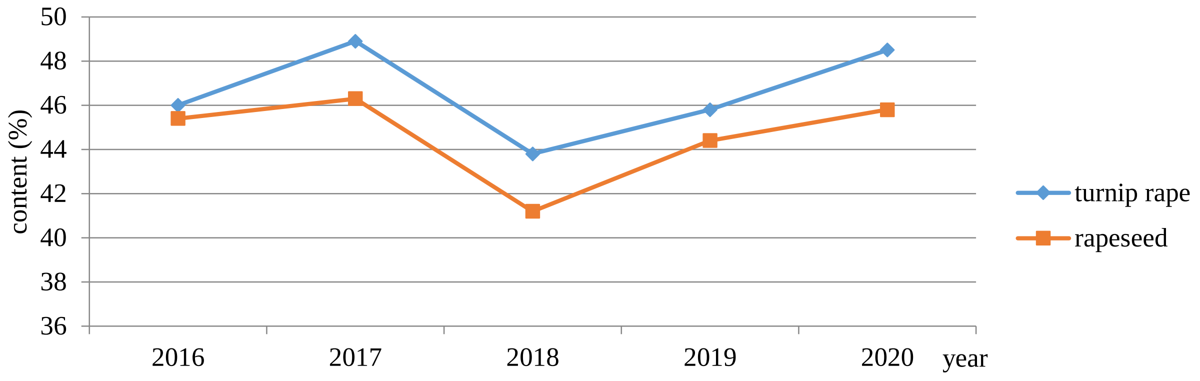

Fig. 2. Oil content of spring rape and turnip rape, based on the conditions of the year.

Turnip rape is an obligate cross-pollinated plant; thus, its varieties are heterogeneous populations. Individual plants with the desired traits were selected from the genetically variable initial population and further evaluated by offspring. In 2015, 220 elite yellow-seeded plants were selected from Zolotistaya (163) and Yantarnaya (57) varieties. The analysis of the oil content and the content of glucosinolates in the seeds of the selected plants showed a low range of variation in oil content and a high range in the content of glucosinolates. In Zolotistaya and Yantarnaya plants, the oil content varied from 38.8 to 51.5% (coefficient of variation CV% = 4.63) and from 40.4 to 51.1% (CV% = 5.12), respectively. The range of variability in the content of glucosinolates is significant in the seeds of both varieties. In Zolotistaya and Yantarnaya plants, it ranged from 7.6 to 46.1 µmol/g (CV% = 57.0) and from 8.6 to 23.6 µmol g^{-1} (CV% = 40.6), respectively (Table 2).

Table 2. Variation of oil and glucosinolate content in the seeds of elite spring turnip rape plants, VNIIMK, 2015.

Variety	Seed oil content %			Glucosinolate content, µmol g^{-1}		
	$\bar{x}$	lim	R	$\bar{x}$	lim	R
Zolotistaya (n=163)	46.4	38.8-51.5	12.7	14.4	7.6-46.1	38.5
Yantarnaya (n = 57)	46.0	40.4-51.1	10.7	12.1	8.6-23.6	15.0

$\bar{x}$- mean,lim: range of variation, R: range of variability.

The offspring of the best plants in terms of oil and glucosinolate content were assessed during 2 years by their main economic characteristics in a breeding nursery. The results showed insignificant differences between the studied samples during the growing season. The range of variability was 4 days in 2016. A slightly increased variability for this feature (6 days) was in 2017 (Table 3). An increase in the duration of the growing season and the variability of the trait is due to the conditions of the year (Table 3).

Table 3. Indicators of variability of breeding samples of spring turnip rape in the breeding nursery by the duration of the growing season and seed yielding capacity.

Year	Number of families, pc.	Growing period, day			Seed yield, (ton ha^{-1})		
		$\bar{x}$	lim	R	×*	lim	R
2016	62	76	74-78	4	1.85	1.38-2.19	0.81
2017	62	85	81-87	6	1.95	1.56-2.29	0.73

$\bar{x}$: Mean, lim: Range of variation, R: Range of variability.

The studied samples had a moderate range of variation by seed yielding capacity, one of the main characteristics in the selection of spring turnip rape. In 2016 and 2017, the coefficient variations were 12.95 and 11.38, respectively. The breeding of modern varieties of spring rape place priority on high oil content, oil quality, as well as the quality of protein, which largely depends on the content of glucosinolates in the seeds. The analysis of the fatty acid composition of the oil showed all the studied samples to be non-erucic; only traces of this acid were found (0.1-0.6%). The standard provides for its content of no more than 2%. Variability in seed oil content was insignificant from 44.5 to 47.4% in 2016 (CV% = 1.26) and from 46.7 to 50.2% in 2017 (CV% = 1.51). Strict rejection by the content of glucosinolates in the seeds of elite plants provided the moderate variability of this trait in their offspring. Range of variation in 2016 and 2017 was 11.7-19.7 μmol g^{-1} (CV% = 13.10) and 10.8 to 17.1 μmol g^{-1} (CV% = 14.56), respectively (Table 4).

Table 4. Indicators of variability of breeding samples of spring turnip rape in the breeding nursery by oil and glucosinolate content in seeds.

Year	Number of families, pc.	Seed oil content %			Glucosinolate content, μmol g^{-1}		
		$\bar{x}$	lim	R	$\bar{x}$	lim	R
2016	62	46.0	44.5-47.4	2.9	14.7	11.7-19.7	8.0
2017	62	48.9	46.7-50.2	3.5	13.3	10.8-18.4	6.3

$\bar{x}$: Mean, lim: Range of variation, R: Range of variability.

As a result of the assessment of a set of economic characteristics at a breeding nursery, 4 promising samples were identified. In extreme conditions of 2018-2020 (strong infestation by cabbage moth in 2018-2019 and heavy rainfalls during the harvesting period in 2020), the selected cultivars demonstrated a seed yielding capacity of 1.93–1.96 ton ha-1, exceeding Zolotistaya standard cultivar by 10-14%, and oil yield by 12-15% (Table 5). The oil content of seeds of the selected samples varied from 47.8 to 48.6% and exceeded the standard variety by 0.3–0.7% in three of them. Promising cultivars either had the same or lower weight of 1000 seeds (2.4-3.0 g), in comparison with Zolotistaya.

Table 5. Economic characteristics of the best samples of spring turnip rape in competitive testing, ARRIOC, 2018-2020.

Sample No.	Growing period, day	Seed yield		Seed oil content, %	Oil yield, ton ha^{-1}	Weight of 1000 seeds, g
		ton ha^{-1}	% to st.			
815	78	1.99	114	48.2	0.86	2.8
844	77	1.96	112	47.8	0.86	2.6
816	77	1.95	111	48.2	0.84	3.0
820	77	1.93	110	48.6	0.84	2.4
Zolotistaya - st.	77	1.75		47.9	0.75	3.0

All selected samples of turnip rape have a low glucosinolate content in seeds – 13.5-14.5 μmol/g; their fatty acid composition meets the requirements for high-quality salad oils with erucic acid concentration of 0.04-0.20% (Table 6). The seeds of all selected samples have a uniform yellow coat.

Table 6. Characteristics of the best samples of spring turnip rape by biochemical parameters, ARRIOC, 2018-2020.

Sample No.	Glucosinolates, μmol g^{-1}	Fatty acid content in oil (%)			
		oleic	linoleic	linolenic	erucic
815	14.5	67.4	20.6	7.9	0.10
844	13.6	66.3	19.4	7.5	0.20
816	13.5	66.0	19.7	8.5	0.10
820	13.9	65.8	19.4	7.9	0.04
Zolotistaya - st.	14.8	65.6	19.8	7.8	0.04

We have created promising cultivars of spring turnip rape with a high-quality composition of oil and meal, consistently high seed yielding capacity and oil content. After the production testing, the best specimen will be submitted for the State testing. The promising growing regions should be the Northern regions of the European part of Russia, as well as Western and Eastern Siberia.

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