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THE ASSESSMENT OF ALLELOPATHIC SENSITIVITY OF OILSEED RADISH (*RAPHANUS SATIVUS L*. VAR. OLEIFORMIS PERS.) TO THE MAIN WEEDS OF ITS AGROCENOSES AT THE STAGE OF INITIAL GROWTH

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Abstract. The article contains the research results on the allelopathic susceptibility of oilseed radish to the main weed species that are dominant in its agrocenoses. The analysis of this indicator involved the research of the allometric reaction of oil radish on the treatment by aqueous extracts of 20 weed species in the concentration range from 1.0 to 4.0% in the period before the formation of true leaves. The morphological reaction to the applied extracts was determined using a number of index indicators assessing the ratio of growth and development of root and aboveground plant systems, the level of morphological depression of plants by linear characteristics, allelopathic potential etc. As a result of research, a dynamic range of harmfulness of the main weed species in terms of allelopathic potential in the range of 0.31-0.57 in relation to oilseed radish plants was established and the possibility of its use for biological control of weeds in the system of modern biologized agrotechnologies was determined.

Key words: Oilseed radish; Allelopathic sensitivity; Allelopathic potential; Plant allometry; Species competition; Extracts; Weeds.

INTRODUCTION

Allelopathic approach in weed population control system isn't new, but it is based on biologic and physiologic regularities of agrocoenosis formation and development, which are based on the principles of vitality strategy of particular plant species and their competition both on the level of intraspecific and interspecific expression in the format of horizontal and vertical gradients (Arroyo, A.I. et al. 2018; Van-Volkenburg, H. et al. 2020). Application of the allelopathic factor is becoming more and more popular worldwide, given the intensive development of organic farming and crop production systems, and the formation of resistance in weeds to widely used active substances of herbicides. The development of this direction is also supported by aspects of climate change, which cause changes in the typology of the nature of the infestation of territories and the dominance of the most aggressive weed species, which are most adapted to the aridization of the territory's hydrothermal regime and are much more competitive than cultivated plant species (Florence, A.M. et al. 2019). The allelopathic activity of traditional cruciferous crops is known and determined by leaching and secretion of glucosinolates, and their hydrolysis to isothiocyanates inhibits germination and growth of weed seeds (Lemerle, D. et al. 2017; Carvalho, M.S.S. et al. 2019). On the other hand, there is a certain tendency for limited application of cruciferous crops in the system of allelopathic control of weeds using traditional white mustard, spring and winter rapeseed.

On the other hand, there is a tendency to limit the use of cruciferous crops in the system of allelopathic weed control traditional white, spring and winter rape mustard.

As for oilseed radish, which has a full complex of beneficial features and belongs to the fodder-green-manure crops used in the system of organic (alternative) farming (Peshkova, A.A., Dorofeev, N.V. 2008), the question of allelopathy is poorly studied in comparison with other similar species*: Raphanus sativus* L. var. *longipinnatus*, *Raphanus sativus* var. *niger* J. Kern (Kunz, Ch. et al. 2016) and even with wild radish species *Raphanus raphanistrum* (Norsworthy, J.K. 2003).

Considering the above-mentioned factors, it is important to establish the level of oilseed radish allelopathic sensitivity to the main weed species with a high frequency of occurrence in its coenoses in the study area in terms of effective use for weed control in crop rotation.

This task has become the goal of our research. The working hypothesis of the research is based on the assumption that the allelopathic potential of oilseed radish is sufficient for its effective use in farming systems with limited use of classical herbicides with the corresponding realization of its allelopathic and weed-competitive potential.

MATERIALS AND METHODS

The research was conducted in the laboratory in 2020 and 2021; it involved the research of the growth and development of oilseed radish during their germination on the substrate to the BBCH 11 phenological stage (Test Guidelines … 2017).

The parts of weed plants were selected in the flowering phase, parts of the root system, stem, leaves and generative part were equal (the share of each element is 20% by weight). Before drying, the plants were washed in running water to remove dust and dirt. The formed sample was ground and dried to form an air-dry mass. The obtained samples were ground to a powder by a laboratory grinder. The range of weed species used in the research corresponded to long-term estimates of their prevalence in oilseed radish agrocenoses in the researched area (Table 1).

The aqueous extracts of weeds were obtained in accordance with generally accepted guidelines (Fujii, Y., Hiradate, S. 2007) with 4.0% and 1.0% concentrations (w / v). An appropriate amount of ground weed sample was placed in a glass container, and an appropriate volume of distilled water was added, it corresponded to the desired extract concentration by weight / volume ratio of liquid. For better extraction, the samples were centrifuged. The extraction took place for 24 hours without access of light in sealed closed vessels made of chemically resistant glass. The extracted solution was poured into a vessel and filtered. The process of laboratory germination involved the use of plastic cassettes with 50c m^3 cells filled with the same well-moistened substrate for all variants, prepared for germination in accordance with bioindication standards (Fujii, Y., Hiradate, S. 2007). Aqueous extracts of the researched weed species were added on the first, fifth and tenth days of germination. One treatment option included 10 cells of one option in five repetitions. The control version of the experiment was watering with distilled water.

Table 1. *Weed species used in research*

Latin Name	Family	Symbol from EPPO codes database
Annual species		
Amaranthus retroflexus L.	Amaranthaceae	AMARE
Ambrosia artemisiifolia L.	Asteraceae	AMBEL
Brassica campestris (L.) Janchen	Brassicaceae	BRSRA
Polygonum lapathifolium (L.) Delarbre	Polygonaceae	POLLA
Chenopodium album L.	Amaranthaceae	CHEAL
Echinochloa crus-galli (L.) P.Beauv.	Poaceae	ECHCG
Erigeron canadensis L.	Asteraceae	ERICA
Galinsoga parviflora Cavanilles	Asteraceae	GASPA
Galium aparine L.	Rubiaceae	GALAP
Lactuca serriola L.	Asteraceae	LACSE
Setaria glauca L.	Poaceae	SETPU
Sinapis arvensis L.	Brassicaceae	SINAR
Raphanus raphanistrum L.	Brassicaceae	RAPRA
Perennial species		
Carduus acanthoides L.	Asteraceae	CRUAC
Sonchus arvensis L.	Asteraceae	SONAR
Agropyron repens (L.) Gould	Poaceae	AGRRE
Cirsium arvense (L.) Scopoli	Asteraceae	CIRAR
Convolvulus arvensis L.	Convolvulaceae	CONAR
Equisetum arvense L.	Equisetaceae	EQUAR
Taraxacum officinale Weber	Asteraceae	TAROF

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The general morphological development of plants was determined in non-adjacent repetitions on the 18th day of the experiment.

The following indicators were used to assess the intensity of plant growth processes:

– Plant development index (%) by formula (1) (Gariglio, N.F. et al. 2002):

$$GI = \left[\frac{G}{G_0} \times \frac{L}{L_0}\right] \times 100, \tag{1}$$

where G – seed germination (%) in each option; G_0 – control seed germination (%); L – average length (mm) of seedling (sum of lengths of aboveground and root systems) in each option; L_0 – average length (mm) of control seedling.

– Allometric coefficient by formula (2) (Nasr, M. & Mansour, S. 2005):

$$CA = \frac{L_s}{L_r}, \tag{2}$$

where L_s – shoot length, a L_r – root length, mm.

– The index of the dry weight plants ratio by formula (3) (Nasr, M. & Mansour, S. 2005):

$$DWR = \frac{DW_s}{DW_r}, \tag{3}$$

where DW_s – shoot dry weight (mg), a DW_r – root dry weight (mg).

– Allelopathic pressure index by formula (4) (Surendra, M.P. & Pota, K.B. 1978):

$$IR = \frac{C - T}{C} \times 100, \tag{4}$$

where C – control parameter (length or biomass of shoot / root); T – the same parameter of the corresponding option.

– Total allelopathic potential by formula (5) (Tiquia, S. et al. 1996; Smith, O.P. 2013):

$$AP = mean(R_a + R_b)/100, \tag{5}$$

where IR_a, – percentage inhibition of seedling growth at the lowest applied concentration (% w/v) and IR_b – percentage inhibition of seedling growth at the highest applied concentration.

The categories used to determine allelopathic potential using OAP score (Smith, O.P. 2013) were 0-0.25 – non-allelopathic (NA); 0.26-0.5 – moderately allelopathic (MA); 0.51-0.75 – highly allelopathic (HA); 0.76-1.0 – extremely allelopathic (EA).

The Intertool MT-3006 electronic caliper was used for linear measurements. Plant weight was determined using electronic laboratory scales Certus CBA-300-0.005.

The dry matter content in plants was determined by the method of thermostatic drying of the consolidated sample of plants obtained in soil-substrate germination on all replicates of the experimental variants (*Fujii, Y., Hiradate, S. 2007*).

The statistical evaluation of all analyzes was performed using the statistical software package Statistica 10.0 for Windows according to the analysis of variance (Hinnkelmann, K., Kempthorne, O. 2019).

RESULTS AND DISCUSSION

The evaluation of allelopathic sensitivity of oilseed radish at the stage of seedling formation with signs of the first true leaves formation was carried out in the context of two variants of concentration (4.0 and 1.0%); it is not accidental. Our researches on the effect of weeds aqueous extracts on the formation of germination of oilseed radish seeds were carried out on filter paper and soil in a number of concentrations of aqueous extracts of weeds (w / v), i.e., 16.0%, 8.0%, 4.0%, 2.0%, 1.0%, 0.5%, 0.25%. The reaction sensitivity to the seed germination formation was established at 0.25 % concentration as a result of the above-mentioned researches, and a significant decrease in laboratory seed germination was observed at 1.0-4.0% concentration. According to A.M. Grodzinsky (1965), such reaction testifies both high allelopathic sensitivity of a species, and its adaptive vitality tactics in own cenosis formation in the general cenosis of competing plant species interactions. According to up-to-date researches (Schandry, N., Becker, C. 2020; Muli, G.K. et al., 2021), allelopathic reaction is noted for many plant species in the range from 0.1% to 32.0. The constant reaction to the intensive decrease in seed germination was at 0.5-1.5%. It is noted (Narwal, S.S. 1994; Smith, O.P. 2013) that the degree of allelopathic reaction is due to the introduction of the species from the standpoint of its cultivation, and from the standpoint of proximity to typical weeds. With long-term agricultural use, the species spectrum of the allelopathic reaction narrows to the most aggressive species, and the allelopathic sensitivity is higher with limited territorial cultivation. It is confirmed by our research taking into account the fact that the intensity of oilseed radish growing is limited in many regions. The assessment of allelopathic effects must be accompanied by an analysis of growth processes in the system of relevant indicators and growth ratios, which will give a complete picture of the target effect of relevant plant extracts on the growth and development of the test object (Table 2).

Table 2. *Effect of weeds water extracts on the initial growth processes of oilseed radish (average for 2020-2021)*

Weed species	Length, mm				Seedling GI (%)		CA		DWR	
	root		stem							
	*4.0	*1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	1.0
Control	31.4	31.4	83.4	83.4			2.8	2.8	5.3	5.3
Annual weeds										
Amaranthus retroflexus L.	8.3	14.6	38.7	47.5	3.3	20.4	4.7	3.3	5.9	7.7
Ambrosia artemisiifolia L.	11.3	16.5	43.1	60.6	10.8	39.4	3.8	3.7	5.5	8.6
Brassica campestris (L.) Janchen	10.5	14.1	38.0	50.9	3.8	24.4	3.6	3.6	5.5	8.4
Polygonum lapathifolium (L.) Delarbre	10.9	17.7	66.8	73.8	13.3	42.2	6.1	4.2	7.4	10.6
Chenopodium album L.	12.2	24.9	33.6	58.7	4.3	24.2	2.8	2.4	2.8	5.6
Echinochloa crus-galli (L.) P.Beauv.	7.2	14.5	42.3	57.0	7.0	36.5	5.9	3.9	6.4	9.3
Erigeron canadensis L.	8.5	15.2	42.4	62.5	21.5	56.5	5.0	4.1	6.6	9.7
Galinsoga parviflora Cavanilles	10.6	29.0	22.5	38.7	4.7	23.5	2.1	1.3	2.6	3.1
Galium aparine L.	14.4	24.9	46.7	75.6	9.6	54.4	3.3	3.0	4.4	7.4
Lactuca serriola L.	10.4	16.8	31.0	41.7	9.5	45.2	3.0	2.5	4.1	5.8
Setaria glauca L.	12.5	24.1	42.1	58.6	2.8	31.2	3.4	2.4	4.1	5.7
Sinapis arvensis L.	14.1	26.4	35.4	63.4	16.3	59.0	2.5	2.4	3.0	5.6
Raphanus raphanistrum L.	10.4	21.3	36.9	60.7	11.3	39.4	3.6	2.8	5.1	6.7
Perennial weeds										
Carduus acanthoides L.	8.0	17.0	38.4	56.2	15.8	44.6	4.8	3.3	5.5	7.8
Sonchus arvensis L.	18.3	28.1	48.9	60.2	5.8	50.4	2.7	2.1	4.0	5.0
Agropyron repens (L.) Gould	11.9	18.9	43.0	48.3	7.2	27.7	3.6	2.5	5.4	6.0
Cirsium arvense (L.) Scopoli	11.4	16.0	30.6	48.8	6.4	23.6	2.7	3.0	4.1	7.2
Convolvulus arvensis L.	16.4	18.7	32.6	55.5	5.8	30.4	2.0	3.0	3.3	7.0
Equisetum arvense L.	12.3	21.1	33.8	41.9	2.3	32.2	2.8	2.0	3.6	4.7
Taraxacum officinale Weber	14.8	25.4	25.5	39.4	8.7	49.0	1.7	1.6	2.2	3.6
$HIP_{0.5}$	0.8	1.2	1.2	1.4	-	-	-	-	-	-

** – concentrations of extracts.*

It was found that the extract effect on growth processes was species-specific with differences in the effect on the root system and stem (aboveground) part. It indicates the relationship between dry matter formation of stem and root systems in DWR format and its comparison with the control variant, and the value of the Coefficient of allometry (CA) in the context of the researched plant species.

The evaluation of the relationships between the morphoparameters of the aboveground and root systems is an important factor in allelopathic analysis, because each plant species is characterized by a certain index of the relationship between the development of stem and root systems. Certainly, this ratio varies depending on the growing conditions, soil and climatic parameters, but it is relatively stable at certain intervals. This fact in the allelopathic analysis is indicated by the results of the Duke's researches (2015). This criterion adequately reflects the intensity and specificity of plant growth processes by dividing them into certain types. Thus, the allelopathic tension between the species is greater under the same type of growth ratio of the aboveground and underground parts of the plant, and the biological and chemical effect of allelopathic substances will affect this ratio.

The researched extracts influenced on the morphological development of plants, i.e., the length of the root system and stem for both variants of the extract concentration. Thus, an aqueous extract of Echinochloa crus-galli (L.) P. Beauv. formed the lowest average length of the oilseed radish root system – 10.8 mm, and the length of the stem part – 49.7 mm. However, aqueous extracts of Sonchus arvensis L. formed these indicators at the level of 23.2 mm and 54.6 mm, respectively. Under the action of aqueous extracts of Polygonum lapathifolium (L.) Delarbre obtained the minimum value of the length of the root system. Extracts of different weed species had significantly different effects on the allometric coefficients and weight (dry matter accumulation). There was a general decrease of both cotyledons and hypocotyl diameter, and deformation of the aboveground part in the absence of significant morphological differences (Figure 1) between the variants of the concentration 1.0% and 4.0% aqueous extract. Regarding the root systems for test plants, certain morphological features of development were also established - from the general elongation of the root system without a pronounced lateral branching (variant Sonchus arvensis L) to intense radial branching with minimal linear elongation (variant Erigeron canadensis L.). Certain morphological features of the test plants root systems development were established, i.e., from the general elongation of the root system without pronounced lateral branching (Sonchus arvensis L) to intense radial branching with minimal linear elongation (Erigeron canadensis L.).

As a result, we found that reducing the concentration of aqueous weed extract from 4.0% to 1.0% reduces the disparity between the stem and root parts ratio as the indicator approaches the control variant and causes the formation of a larger aboveground mass and the corresponding dry matter. This ratios dynamic indicates the dominant extracts effect on the root system formation, and intense effect on both the root and stem part of species with high allelopathic potential. However, there are corresponding exceptions. Thus, the increase in CA with a decrease in concentration was observed under the influence of species such as Cirsium arvense (L.) Scopoli, Convolvulus arvensis L. The levels of CA value for both concentrations indicating a unidirectional effect on the growth processes of the aboveground and underground parts, were observed under the influence of such species as Brassica campestris (L.) Janchen, Taraxacum officinale Weber.

We have also found that the average value of allometric growth coefficient of oilseed radish plants was also set at 3.6 for annual weed extracts and 2.9 for perennial weed extracts.

The annuals reduce the length of the root system, and the length of the stem part of radish oil plants more actively. We observed an identical effect on the lengths of both parts and their ratios by water extracts of perennial weeds with higher allelopathic pressure and a smaller size of the root and stem part. Researched data give us reason to positively assess the potential of oilseed radish by its allelopathic interaction with researched weeds considering other cruciferous crops assessment carried out by scholars all over the world (Lemerle, D. et al. 2014; Rehman, S. et al. 2019; Khan, S. et al. 2019).

The allelopathic pressure of the researched weeds aqueous extracts by the integrated indicator, including the averaging of CA, GI and DRW, allowed us to place these species in the order of coenotic sensitivity of oilseed radish for germination on soil substrate for annual species (in ascending order), i.e., *Polygonum lapathifolium* (L.) Delarbre – *Galium aparine L.– Sinapis arvensis L.– Setaria glauca* L.– *Ambrosia artemisiifolia L.– Raphanus raphanistrum* L.– *Chenopodium album* L.– *Erigeron canadensis* L. – *Polygonum lapathifolium* (L.) Delarbre – *Brassica campestris* (L.) Janchen – *Amaranthus retroflexus L.– Galinsoga parviflora* Cavanilles – *Lactuca serriola* L.. *This order has the following form for the researched* *perennial weeds: Sonchus arvensis* L. – *Convolvulus arvensis* L.– *Agropyron repens* (L.) Gould – *Carduus acanthoides* L.– *Equisetum arvense* L.– *Cirsium arvense* (L.) Scopoli – *Taraxacum officinale* Weber.

Figure 1. Oilseed radish plants selected from one cell of the cassette of one replication cultivated in the soil substrate and obtained in variants of three aqueous extracts of weeds at successive solution concentrations (left-right) 4.0, 2.0 and 1.0%, 2020. (1 – *Galium aparine* L., 2 – *Ambrosia artemisiifolia* L., 3 – *Setaria glauca* L., 4 – *Erigeron canadensis* L., 5 – *Carduus acanthoides* L., 6 – *Cirsium arvense* (L.) Scopoli, 7 – *Echinochloa crus-galli* (L.) P.Beauv., 8 – *Brassica campestris* (L.) Janchen, *9 – Agropyron repens* (L.) Gould*, 10 – Amaranthus retroflexus* L.*, 11 – Taraxacum officinale* Weber*, 12 – Sonchus arvensis* L.*, 13 – Raphanus raphanistrum* L.*, 14 – Galinsoga parviflora* Cavanilles*, 15 – Chenopodium album L., 16 – Convolvulus arvensis* L.*, 17 – Equisetum arvense* L., 18 – *Lactuca serriola* L.*)*

It should also be noted that the extracts of different weed species had different effects on the linear size of the root system and stem, the structure of the tissues, it also affected the dry matter content. Thus, for the value of the DWR ratio, disparity growth of root and above-ground parts by 18-30% was observed in comparison with the value of raw mass of parts of oil radish plants in the value of the allelometry coefficient (CA). The data obtained by us allowed to divide researched weed species by allelopathic activity in relation to oilseed radish as the test object (Table 3).

We should note that the allelopathic potential indicator is a measure of the allelopathic effect in the weed-plant tester system. It shows the level of competitiveness of the tester plant in relation to a particular weed species without taking into account the rate of vegetation growth and the level of its vitality tactics and other factors. However, it divides the species according to the threshold value of the important starting competition, which essentially determines the subsequent success of the formation of the agrocenosis of any cultivated plant. According to the proposed gradation of AR, oilseed radish can be attributed to species with high competition potential in relation to the main weed species where this figure was 0.55.

According to the allelopathic potential indicator taking into account growth processes of oilseed radish and giving the prevalence to certain species in its agrocenoses, the main harmful weed species can be placed in the following order: sow thistles (AP = 0.31) – pigeon grass (0.38) – pale persicaria (0.43) – lamb's quarters (0.43) – common ragweed (0.45) – field bindweed (0.46) – water grass (0.51) – field horsetail (0.51) – potato weed (0.52) – field thistle (0.54) – red-root amaranth (0.55) – prickly lettuce (0,57). It should also be noted that radish oil has a higher level of tolerance in assessing the formation of laboratory germination and initial growth processes in contrast to other crops investigated in similar researches (Marinov-Serafimov, P. et al. 2019), although allelopathic influence on basic indicators has certain similar features.

Table 3. *Allelopathic potential (AP) of weeds for oilseed radish growth (for the ratio of concentrations of 4.0% to 1.0% for cultivation on soil substrate) (average for 2020-2021)*

Weed species	Root	Stem	Seedling	Average value
Annual weeds				
Amaranthus retroflexus L.	0.64	0.48	0.53	0.55
Ambrosia artemisiifolia L.	0.56	0.38	0.43	0.45
Brassica campestris (L.) Janchen	0.61	0.47	0.51	0.53
Polygonum lapathifolium (L.) Delarbre	0.54	0.36	0.45	0.44
Chenopodium album L.	0.47	0.55	0.51	0.43
Echinochloa crus-galli (L.) P.Beauv.	0.65	0.41	0.47	0.51
Erigeron canadensis L.	0.62	0.37	0.44	0.48
Galinsoga parviflora Cavanilles	0.37	0.63	0.56	0.52
Galium aparine L.	0.37	0.27	0.30	0.31
Lactuca serriola L.	0.57	0.56	0.57	0.57
Setaria glauca L.	0.42	0.40	0.40	0.40
Sinapis arvensis L.	0.35	0.41	0.39	0.38
Raphanus raphanistrum L.	0.49	0.41	0.44	0.45
Perennial weeds				
Carduus acanthoides L.	0.60	0.43	0.48	0.51
Sonchus arvensis L.	0.26	0.35	0.32	0.31
Agropyron repens (L.) Gould	0.51	0.45	0.47	0.48
Cirsium arvense (L.) Scopoli	0.56	0.52	0.53	0.54
Convolvulus arvensis L.	0.44	0.47	0.46	0.46
Equisetum arvense L.	0.47	0.55	0.53	0.51
Taraxacum officinale Weber	0.36	0.61	0.54	0.50
$HIP_{0,5}$	*0.038*	*0.045*	*0.037*	–

Considering the allelopathic potential of the researched species for oilseed radish, the overall harmfulness of weed types will increase in the following order: perennial – rhizome – perennial-rhizome – root-sprouting – perennial root-sprouting – rhizome root-sprouting – perennial rhizome root-sprouting. At the same time, the maximum allelopathic pressure in the cenosis of oilseed radish will be reached for the share of weed species with allelopathic potential over 0.50 at the level of 30%.

Taking into account the principles of fundamental allelopathy (Hrodzynskyi, A.M. 1991; Matveev, N.M. 1994; Smith, O.P. 2013) it should be noted that oil radish is able to actively suppress and compete with weed species which allelopathic potential (AP) is lower and significantly below the level of 0.50.

CONCLUSIONS

Thus, the oilseed radish is a species with a moderate level of allelopathic potential the main weed species in its cenoses in the range of 0.26-0.57 by allelopathic sensitivity at the stage of seedling formation to the phase of formation of true leaves. The allelopathic relationships allows us to recommend the use of radish for alternative farming systems in various intermediate cultivation options to reduce the number of major field contaminants such as *Sonchus arvensis* L., *Setaria glauca* L., *Polygonum lapathifolium* (L.) Delarbre, *Chenopodium album* L., *Ambrosia artemisiifolia* L., *Convolvulus arvensis* L.; the allelopathic sensitivity of oilseed radish to them is lower than 0.50.

Considering the effect of perennial weeds, such as *Carduus acanthoides* L. *Sonchus arvensis* L. *Agropyron repens* (L.) Gould, on the growth processes of oilseed radish plants – limiting its numbers will be effective through the application of increased seeding rates of oilseed radish at 4.0 million units per ha of similar seeds.

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