Journal of Agricultural Science; Vol. 6, No. 11; 2014
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Metabolites of Terrestrial Plants and Marine Organisms as Potential Regulators of Growth of Agricultural Plants in the Russian Far East

M. M. Anisimov[1] & A. G. Klykov[2]

[1] The Pacific Institute of Bioorganic Chemistry named after G. B. Elyakov, the Far Eastern Branch of Russian Academy of Sciences, Vladivostok, Russia

[2] Primorsky Scientific Research Institute of Agriculture of Russian Academy of Agricultural Sciences, Ussuriisky district, Primorsky Krai, Russia

Correspondence: M. M. Anisimov, The Pacific Institute of Bioorganic Chemistry named after G. B. Elyakov, the Far Eastern Branch of Russian Academy of Sciences, N159, Avenue of 100 years of Vladivostok, Vladivostok 690022, Russia. Tel: 7-914-331-0021. E-mail: anisimov@piboc.dvo.ru

Received: July 28, 2014 Accepted: August 28, 2014 Online Published: October 15, 2014

doi:10.5539/jas.v6n11p88 URL: http://dx.doi.org/10.5539/jas.v6n11p88

Abstract

Growth regulating activity of metabolites of terrestrial plants and marine organisms – water, alcohol and lipidic extracts, polysaccharides, diterpene, triterpene and steroidal glycosides, alkaloids, pigments, decumbenones and β,β'-triketones were studied. It was defined that some of the studied substances are capable to stimulate, inhibit or be inactive in relation to the main root of seedlings of agricultural plants. Extract and triterpene glycoside of hederagenin cauloside C, isolated from *Caulophyllum robustum* Maxim., and monosulfated cucumariosides group A_2, isolated from of the Far Eastern edible holothurian *Cucumaria japonica,* inhibit the growth of seedlings the main root of *Cucumis sativus.* Among of decumbenones A (1), B (2) and C (3), isolated from the marine-derived strain of the fungus *Aspergillus sulphureus,* decumbenone A (1) stimulates the growth of seedling roots of *Triticum aestivum* and *Zea mays*. Among of alkaloids 1-9, isolated from the marine fungus *Aspergillus fumigatus,* of alkaloid 3 stimulated the growth of seedling roots of *Orysa sativa* and *Fagopyrum esculentum*. The water extracts of *F. esculentum* (of the red-stem population) at a concentration of 10^{-8} g/ml stimulated productivity of one plant *F. esculentum* by 67% and content of rutin in *F. esculentum* plants by 20% more than in the control.

Keywords: decumbenones, diterpene, triterpene and steroidal glycosides, pigments, polysaccharides, *β,β'*-triketones, alcohol and lipidic extracts, *Cucumis sativus*, *Orysa sativa*, *Fagopyrum esculentum*, *Glycine max*, *Zea mays*, *Triticum aestivum*, *Hordeum vulgare*

1. Introduction

One of the promising directions in agriculture is rational use of local raw material sources for biologically active substances – plant growth stimulators. Plant growth stimulators improve seed germination, seedling development, accelerate growth and yield of the plants (Kumari et al., 2011; Craigie, 2011; Ahmed & Shalaby, 2012; Yurchenko et al., 2013). They are used against pests (Hong et al., 2007) and plant diseases (Jayaraj et al., 2008). They also increase plants resistance to environmental stresses (Zhang & Ervin, 2004, 2008). It is obvious that the main focus should be on the first stages of plant ontogenesis, beginning with seed germination and seedling growth. In the early stages of plant growth is well developed root system provides a sound basis for the value and quality of future crop. Therefore the search for the most effective substances that stimulate its development, should be considered as a priority.

Natural world of the Far East has great potential for the detection and isolation of biologically active compounds that can increase productivity of agricultural plants in the zone of risky agriculture. Terrestrial plants, algae and marine microorganisms can be sources of such biologically active substances.

2. Extracts of Terrestrial Plants

A wide spectrum of medical and biological actions of ginseng roots (*Panax ginseng* C. A. Meyer) is connected with the presence of triterpene glycosides of dammarane and oleanolic series – ginsenosides and panaxasides (Uvarova et al., 2000). However, effect of ginseng roots extracts on plant cells are shown for the first time. The results showed that while having the extracts in concentration of 0.1 and 1.0 mg/ml, the average length of the main root of *Cucumis sativus* seedlings decreased by 8.0, 11.5%, respectively. Extracts have primarily effective influence on rapidly growing seedlings. At the same time, slow growing seedlings were not sensitive to high concentrations of these substances (Anisimov et al., 2003).

East Asian plant *Caulophyllum robustum* Maxim, family *Berberidaceae* Juss., is a source of biologically active substances with a wide range of medical and biological action (Anisimov et al., 2000a). Here is the data influence of water–alcohol extract (WAE) made of roots and rhizomes of *Caulophyllum robustum* upon growth of the main root seedlings of *C. sativus* (Anisimov et al., 2000b). WAE had a significant inhibitory effect on the growth of the main root seedlings of *C. sativus* at concentrations 0.003% and 0.03%. Vigorously growing seedlings are the most sensitive to the inhibitory action of WAE. Thus, WAE reduced the number of sprouts with the root length of 61–80 and 81–100 mm by 70 and 100% at a concentration of 0.003 and 0.03% respectively. Seedlings with slowly growing roots were insensitive to high concentrations of WAE.

The authors studied effect of the extracts of *F. esculentum* (red-stem and red-flower population) – 10^{-8} g/ml and (pink-flower population) – 10^{-6} g/ml) upon the growth and development of *F. esculentum* in blooming stage. The results showed that extracts of *F. esculentum* (red-stem population) at concentration of 10^{-8} g/ml had maximum stimulating effect upon increasing productivity of one plant till 59–67%, and rutin content by 20% more than in the control. Extract from pink- flower population of *F. esculentum* at concentration of 10^{-6} g/ml stimulated maximum increase of 1000 grains weight of *F. esculentum* by 17.7% in comparison with the control (Klykov et al., 2014).

The authors studied effect of plant polysaccharides of *Ampelopsis japonica* Thunb (1), *Angelica dahurica* (liisch. ex Hoffm) (2), *Glehnia littoralis* F. Schmidt (3), *Heracleum moellendorffii* Hance (4), *Saposhnicovia divaricata* (Turez) (5) and *F. esculentum* Moench (6) upon the main root of *C. sativus* seedlings growth. By activity they can be divided into three groups. The first group includes polysaccharides that stimulate root growth. These are polysaccharides of aqueous, oxalate and alkaline extractions from roots of *A. dahurica*, aqueous extraction of *G. littoralis* roots and alkaline extraction from *F. esculentum* fruit shells. The second group of polysaccharides inhibited the roots growth. It includes polysaccharides of alkaline extraction from roots of *A. japonica*, of oxalate extraction from roots, and of water, oxalate and alkaline extractions from *H. moellendorffii* stems, and of water extraction from leaves and stems of *S. divaricata*. Polysaccharides of the third group had no significant effect upon the growth of seedling roots of *S. sativus* (Anisimov et al., 2005).

Saps of different types of *Kalanchoe* Adans demonstrate antifungal (Misra & Dixit, 1979), antihistaminic (Nassis et al., 1992), immunosuppressive (Moraes et al., 1994), antileishmanial (Da-Silva et al., 1995, 1999), insecticidal (Supratman et al., 2000, 2001), hepatoprotective (Yadav & Dixit, 2003), and antiinflammatory activity (Costa et al., 2006). There was investigated growth regulating activity of different classes of lipids (triacylglycerols, free fatty acids, glyceroglycolipids – monogalactosyldiacylglycerol, sulfoquinovosyldiacylglycerol), sterols, derived from herb *Kalanchoe daigremontiana,* and also colorants, phenolic compounds, polysaccharides and the plant ethanolic extract. It was established that ethanolic extract, polysaccharide 2, phenolic components and free fatty acids stimulate the seedlings stem growth of *F. esculentum* by 14% at a concentration of 0.1 μg/ml (Anisimov et al., 2009).

3. Seaweed

Seaweeds resources are intensively used to improve harvest quantity and quality in agriculture and horticulture. Beneficial effect of seaweed products on cultivated plants has been studied well. Usage of seaweed products improve seeds germination, seedlings development and increase plant growth and yield (Hong et al., 2007; Zodape et al., 2008; Khan et al., 2009; Kumari et al., 2011; Craigie, 2011). Seaweeds are used in pests control (Hong et al., 2007) and plant diseases management (Jayaraj et al., 2008). They increase plants' resistance to ecological stresses (Zhang & Ervin, 2004, 2008). Liquid extracts derived from seaweeds gained importance as foliar sprays and soil drench for many crops including various grasses, cereals, flowers (Gandhiyappan & Perumal, 2001; Kumari et al., 2011).

The Far Eastern Marine areas have great biodiversity of algae suitable for food purposes, and for production of pharmacologically active substances and plant growth regulators. Aqueous extracts of marine algae collected at different times of the year, have a stimulating and inhibitory effects on the growth of seedling roots of *F. esculentum* and *G. max* (Anisimov et al., 2013; Anisimov & Chaikina, 2014). Extract of red algae *Neorhodomela larix*, collected in January and May 2012, stimulated growth of seedling roots of *F. esculentum* by 13 and 12% at concentrations of 10^{-5} and 10^{-6} g/ml respectively. Extract of red algae *Tichocarpus crinitus*, collected in May and August 2012, stimulated growth of *Fagopyrum esculentum* roots by 13 and 17% at concentration of 10^{-4} g/ml.

Aqueous extracts of brown algae *Saccharina japonica* and *Sargassum pallidum,* collected in January and May 2012, stimulated growth of seedling roots of *F. esculentum* by 15% and 13% at concentration of 10^{-6} and 10^{-5} g/ml. respectively. Aqueous extract of green alga *Codium fragile*, collected in November 2011, stimulated growth of seedling roots of *G. max* by 18% at concentrations of 10^{-5} g/ml. Aqueous extracts of the most algae have inhibitory effect upon growth of seedling roots of *F. esculentum* and *G. max* at concentrations of 10^{-2} g/ml. Thus, aqueous extracts of algae, depending on the season, have stimulating effect in varying degrees upon growth of seedling roots of *F. esculentum* and *G. max* at concentrations of 10^{-3}–10^{-6} g/ml.

In the bay of Troitsy (the Sea of Japan) in summer there were collected the following sea weeds: *Laminaria cichorioides*, *L. japonica*, *Fucus evanescens*, *Dictyopheris divaricata*, *Costaria costata*, *Sargassum miyabei*, *Scaphecinus mirabilis*, *Punctaria sp.*, *Cocophora langsdorfii*, *Undaria pinnatifida*, *Chorda filum*, *Chordaria flagelliformis*. Lipid fractions were derived from these sea weeds. Effect of the lipid fractions upon growth of the seedlings roots of *F. esculentum* was studied (Anisimov et al., 2010a). It is shown that lipid fractions derived from *L. cichorioides*, *C. langsdorfii*, *U. pinnatifida* demonstrated stimulatory effect on growth of the seedlings roots of *F. esculentum* by 13, 13–17 and 12–17% at concentrations of 0.01, 0.1–10, 1–100 µg/ml, respectively. Lipid fractions from *D. divaricata* – had inhibitory effect on growth of the seedlings roots of buckwheat. Extracts of *L. japonica and F. evanescens* showed stimulatory effect upon growth of the seedlings roots of *G. max* by 20 and 24%, and upon stem growth – 26 and 15%, respectively, at concentrations of 100 µg/ml. These extracts increased productivity of *G. max* by 15.6 and 11.7%. Extracts of *L. sichorioides* and *C. costata* showed less activity. They increased yield by 8.9% (Imbs et al., 2011).

The effect of extractive substances from brown alga *L. cichorioides* on growth of *F. esculentum* sprouts, upon the seeds yield and rutin content in plants was studied. Maximum stimulating effect on growth of seedlings roots of buckwheat was made by chlorophyll, fucoxanthin, digalactosyldiacylglycerol and sulfoquinovosyldiacylglycerol at concentration of 1 µg/ml. Fractions of polyphenolic compounds, monogalactosyldiacylglycerins, sulfoquinovosyldiacylglycerols, fatty acids and fucoxanthin at concentration of 100 µg/ml had inhibiting effect upon the growth of buckwheat stems. Buckwheat seeds treated with an ethanol extract of *L. cichorioides* increased yield of *F. esculentum* (Chaikina et al., 2011).

There was investigated influence of brown seaweed polysaccharides upon the growth of seedlings root and stalk of *G. max* and *F. esculentum*. It was defined, that laminaran derived from *L. cichorioides* – 1,3; 1,6-β-D-glucan (1,3:1,6 ratio is equal to 90:10) (Zvyagintseva et al., 1998), had stimulating effect upon growth of seedlings root of *G. max* by 20% at concentration of 10 µg/ml. Antivir – 1,3; 1,6-β-D-glucan (1,3:1,6 ratio is equal to 80:20) – product of fermentative transformation –laminaran derived from *L. cichorioides* (Zvyagintseva et al., 1998), had stimulating effect upon growth of seedlings root and stem of *G. max* by 50% at concentrations of 10 and 100 µg/ml. Sulfated polysaccharide – fucoidan, derived from *L. cichorioides,* had inhibitory effect upon growth of seedlings roots and stem of G. max by 52.2 and 41.8% at concentration of 100 µg/ml. Polysaccharide (fucoidan and mannuronana mixture) derived from *U. pinnatifida* has stimulating effect upon growth of seedlings root of *F. esculentum* by 16.7% at concentration of 10 µg/ml (Chaikina et al., 2009).

There was studied effect of laminaran and a number of 1,3;1,6-β-*D*-glucooligosaccharides of various molecular masses and branching upon germination of seeds and formation of germs of *F. esculentum* variety Izumrud. It was defined that all the glucans had enhanced the energy of seed germination to various extents and stimulate growth of root of buckwheat germs on the earliest stage (1–2 days). The best stimulating effect had 1,3;1,6-β-*D*-glucooligosaccharides with the molecular mass of 1661.5, characteristic feature of the structure of which is not only presence of a great amount of β-1,6-linked glucose residues as a kind of branches (1,3 : 1,6 = 3.7 : 1), but also presence of a β-1,6-link inside their main chain (Fedorova et al., 2010). β-D-Glucooligosaccharides and fucoidan from seaweed *L. cichorioides* and *F. evanescens,* stimulated productivity of *G. max* by 0,41 and 0,39 t/ha and reduce length of vegetation period by 3–4 days, compared with the control (Zaostrovnyh et al., 2010).

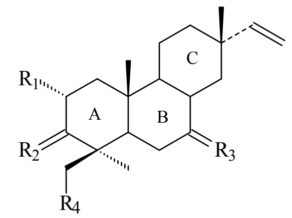
4. Marine Fungi

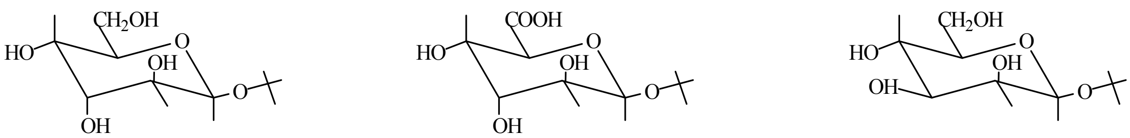
Recent years' studies proved that marine fungi are promising sources of new structural and biologically active secondary metabolites (Bhadury et al., 2006; Debbab et al., 2010; Greve et al., 2010; Proksch et al., 2010; Rateb & Ebel, 2011).

4.1 Diterpene Glycosides

The article presents data on the effect of diterpene glycosides (Table 1) derived from marine fungus *Acremonium striatisporum* on the growth of seedling roots of *Z. mays*. Depending on the chemical structure, virescenosides A-V (1-10) have different effects on the growth of seedling roots of *Z. mays*.

Table 1. Chemical structure of diterpene glycosides derived from marine fungus *Acremonium striatisporum*

	R_1	R_2	R_3	R_4	Δ
					
1	OH	H, *β*-OH	H	*β*-D-Alt*p*	$\Delta^{7,8}$
2	H	H, *β*-OH	H	*β*-D-Alt*p*	$\Delta^{7,8}$
3	H	O	H	*β*-D-Alt*p*	$\Delta^{7,8}$
4	OH	H, *β*-OH	H	*β*-D-Alt*p*A	$\Delta^{7,8}$
5	H	H, *β*-OH	H	*β*-D-Alt*p*A	$\Delta^{7,8}$
6	OH	H, *β*-OH	O	*β*-D-Alt*p*	$\Delta^{8,9}$
7	OH	H, *β*-OH	H, α-OH	*β*-D-Alt*p*	$\Delta^{8,14}$
8	H	H, *β*-OH	O	*β*-D-Alt*p*	$\Delta^{8,9}$
9	H	H, *β*-OH	H	*β*-D-Man*p*	$\Delta^{7,8}$
10	OH	H, *β*-OH	O	*β*-D-Alt*p*	$\Delta^{8,14}$



β-D-altropyranose *β*-D-altropyrauronose *β*-D-mannopyranose

Figure 1. Chemical structure of diterpene glycosides

Thus virescenosides A (1), B (2) and C (3) differ from each other by structure of ring A of aglycone. Virescenoside A (1) has R_1 = OH, R_2 = H, β-OH. This compound showed a stimulant effect on the growth of seedlings root of *Z. mays* at a concentration of 10^{-5} M (by 13.7%). Virescenoside B (2) has R_1 = H. This compound demonstrated the most effective stimulant effect on the growth of seedlings root of *Z. mays* at a concentration of 10^{-6}–10^{-7} M (by 16.0%). Virescenoside C (3) has R_2 = O. This compound showed low stimulant effect on the growth of seedlings root of *Z. mays* at a concentration of 10^{-5} M (by 8.3%). Virescenoside F (4) in contrast to virescenoside A (1), comprises Altruron acid (AltA) as the sugar component, that deprives glucoside 4 of its stimulant effect at a concentration of 10^{-5} – 10^{-8} M. Virescenosides G (5) and Q (9), compared with the glycoside 2, contain respectively AltA and mannose in carbohydrate part. This change for glucoside 5 does not essentially effect on the growth of seedlings root of *Z. mays* (10^{-7} M – 12%), but for glucoside 9, this effect significantly decreases (10^{-5} M – 11%). Virescenoside M (6), N (7), P (8) and V (10) were inactive (Anisimov et al., 2010). There was studied reaction of plant *F. esculentum* (the root system development, changes of morphological traits, yield and content of routine) under usage of diterpene glycoside virescenoside A and the sum of glycosides in small concentrations (10^{-13} – 10^{-15} M) (Klykov et al., 2013). The maximum stimulant effect on seedlings of *F. esculentum* (variety Izumrud) was observed at a concentration of virescenoside A of 10^{-13} M and the sum of glycosides of 10^{-15} M. Stimulant effect of virescenoside A on seedlings of *F. esculentum* (variety Pri 10) was observed at a concentration of 10^{-15} M. Maximum content of rutin in seedlings of *F. esculentum* (variety Izumrud) was observed at a concentration of virescenoside A of 10^{-15}M.

4.2 The Decumbenones A (1), B (2) and C (3)

There was also studied effect of decumbenones A (1), B (2) and C (3) (Figure 2), derived from marine- fungus *Aspergillus sulphureus,* on the growth of seedling roots of buckwheat, wheat, barley and corn at concentration range 10^{-5} – 10^{-18} M. Decumbenone A showed stimulant effect upon growth of seedling roots of *Triticum aestivum* by 14% (10^{-6} M) and *Zea mays* by 27% (10^{-8} M). This compound had not effect upon seedling roots of *Hordeum vulgare* and *F. esculentum*. Decumbenone B showed stimulant effect on growth of seedling roots of *F. esculentum* by 11% (10^{-6} M), *T. aestivum* by 8% (10^{-9} M), *H. vulgare* by 9 % (10^{-7} M) and *Z. mays* by 13% (10^{-8} M). Decumbenone C showed stimulant effect on growth of seedling roots of *H. vulgare* by 17% (10^{-7} M) and *Z. mays* – by 10% (10^{-6} M). This compound had weak stimulant effect on growth of seedling roots of *T. aestivum* by 7% (10^{-8} M) and *F. esculentum* – by 7% (10^{-7} M) (Anisimov et al., 2012a).

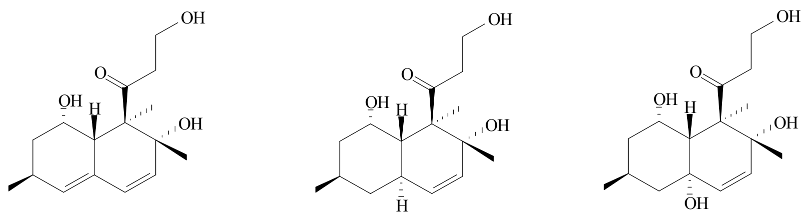


Figure 2. Chemical structure of decumbenones

4.3 The Alkaloids 1–9

The article presents data about effect of alkaloids (1-9) (Figure 3), derived from marine fungus *Aspergillus fumigatus,* upon growth of seedling roots of *F. esculentum, G. max* and *Z. mays*. The alkaloid 1 showed a stimulant effect on the growthof seedling roots of *F. esculentum* by 10% (10^{-9} M)*, G. max* by 10% (10^{-10} M) and *Z. mays* by 13% (10^{-5} M). The alkaloid 2, in which the 12th and 13th hydroxyl groups are replaced by hydrogen atoms, showed inhibitory effect on the growth of seedlings root of *F. esculentum* by 14.3% (10^{-9} M) and stimulant effect on the growth of seedlings roots of *G. max* by 12% (10^{-12} M) and *Z. mays* by 8% (10^{-9} M). The alkaloid 3 showed stimulant effect on the growth of seedlings roots of *F. esculentum* by 21% (10^{-7} M), *G. max* by 14% (10^{-10} M) and didn't show stimulant effect on the growth of seedlings roots of *Z. mays* in studied concentrations. The alkaloid 4 showed stimulant effect on growth of seedlings roots of *F. esculentum* by 14 % and 13 % (10^{-7} and 10^{-12} M respectively) and didn't show stimulant effect on growth of seedlings roots of *G. max* and *Z. mays* in studied concentrations. The alkaloid 5, which differed from alkaloid 1 by additional prenyl residue and endoperoxide bond, showed stimulant effect on growth of seedlings roots of *G. max* by 10% (10^{-7} M) and didn't effect upon growth of seedlings roots of *F. esculentum* and *Zea mays.* The alkaloid 6 showed stimulant effect on growth of seedlings roots of *F. esculentum*, *G. max* and *Z. mays* by 17 %, 12 % and 13 % (10^{-10}, 10^{-10} and 10^{-7} M) respectively. The alkaloid 7 showed stimulant effect on growth of seedlings roots of *F. esculentum*, *G. max* and *Z. mays* by 13 %, 16 % and 17 % (10^{-8}, 10^{-9} and 10^{-9} M) respectively. The alkaloids 8 showed the most expressed stimulant effect on growth of seedlings roots of *Z. mays* by 21, 17 and 18% (10^{-15}, 10^{-10} and 10^{-5} M), respectively, while it didn't effect upon roots of seedlings of *F. esculentum* and *G. max*. The alkaloids 9 didn't effect upon roots of seedlings of *F. esculentum* (Anisimov et al., 2012b, 2013; Afiyatullov et al., 2012).

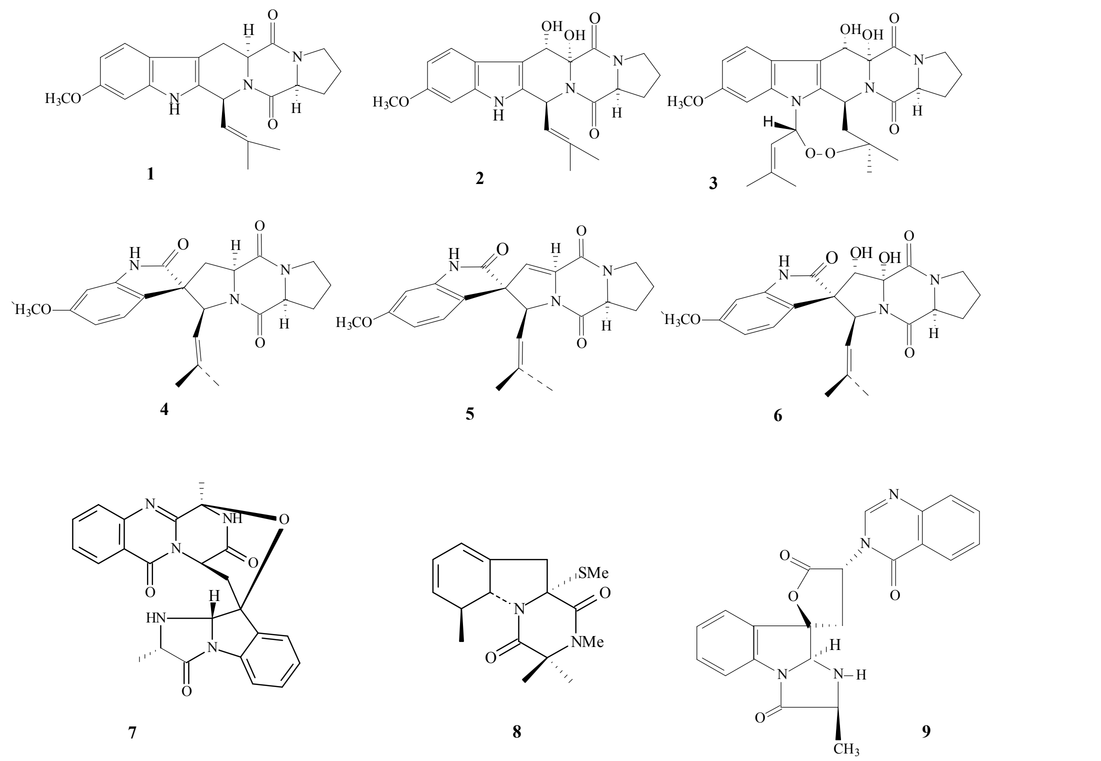
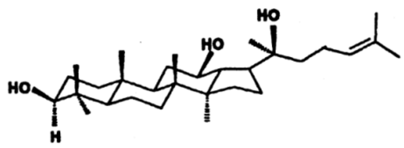


Figure 3. Chemical structure of alkaloids

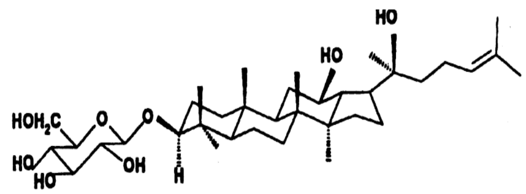
5. The Triterpene

5.1 Triterpene Glycosides of Dammarane Series and Their Analogues

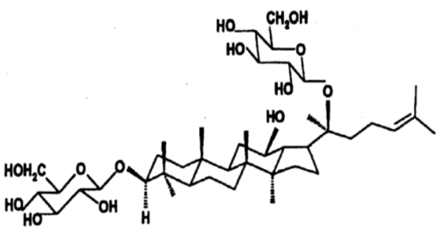
Triterpene glycosides derived from *Panax ginseng* are worthy of notice as plant growth regulators. There was studied effect of triterpene glycosides – 20(S)-protopanaxadiol (1), two semisynthetic glycosides identical with ginsenosides Rh_2 (2) and F_2 (3), and ginsenoside Rb_1 (4) (Figure 4), upon growth of seedlings root of *C. sativus*. For the first time it has been shown that 20(S)-protopanaxadiol (1) has an inhibitory effect on growth of seedlings root of *C. sativus* (11.2%) at a concentration of 100 µg/ml and has a stimulant effect (13.1%) at a concentration of 0.1 µg/ml. Seedlings with high growth energy were more sensitive to this compound. The rest substances 2, 3 and 4 did not show activity at concentrations range 1–100 µg/ml (Stekhova et al., 2001). Dammar-24-en-12β,17α,20(S)-tetraol (betulafolientetraol), derived from non-saponine part of ethereal extract of *Betula pendula* Roth leaves (Pohilo & Uvarova, 1988), has inhibitory effect on growth of seedlings' main root of *C. sativus* (17.7%) at a concentration of 100 µg/ml. Seedlings with high growth energy were more sensitive to dammar-24-en-12β,17*α,*20(S)-tetraol (Anisimov et al., 1998).



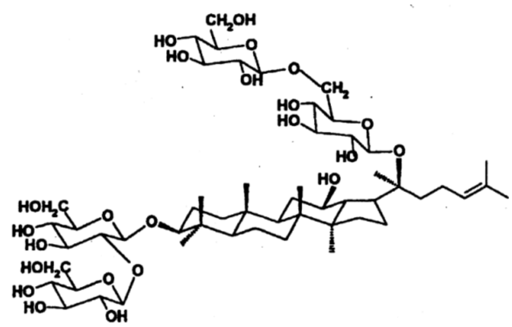
20(S)-Protopanaxadiol (1)



Ginsenosides–Rh$_2$ (2)



Ginsenosides–F$_2$ (3)

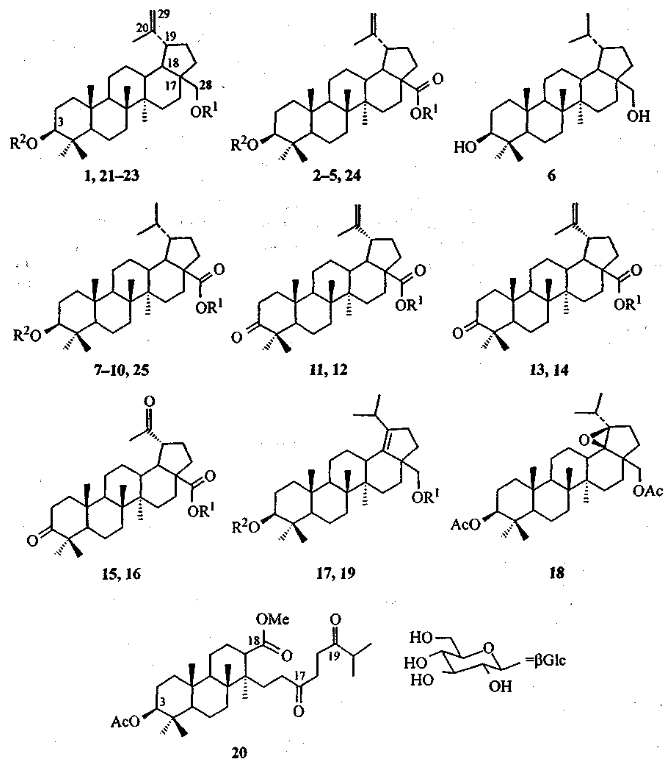


Ginsenoside–Rb$_1$ (4)

Figure 4. Chemical structure of triterpene glycosides of dammarane series and their analogues

5.2 The Triterpenoids of Lupane Series

Influence of triterpenoids of lupane series (Figure 5) upon growth of seedlings roots of *C. sativus* was investigated. It is shown that these compounds (1–25) hadn't obvious effect of the plant growth regulators in concentrations 0.001-100.00 µg/ml (Stekhova et al., 2002; Anisimov et al., 2006).

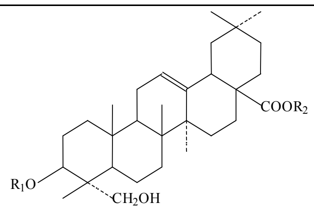


R^1 = H (1–3, 7, 8, 11, 13, 15, 17, 22, 24, 25); Me (19); βGlc (4, 5, 9, 10, 12, 14, 16, 21, 23)
R^2 = H (1, 2, 7, 11, 17, 24); Ac (19, 24, 25); βGlc (5, 8, 10, 21, 22)

Figure 5. Chemical structure of triterpenoids of lupane series

5.3. Triterpene Glycosides of Hederagenin

Table 2. Chemical structure of triterpene glycosides of hederagenin

Substances	**R_1**	**R_2**
		
Hederagenin	H	H
Cauloside A	α-L-Arap–	H
Cauloside C	β-D-Glcp-(1→2)-α-L-Arap–	H
Cauloside D	α-L-Arap–	–β-D-Glcp-(6←1)-β-D-Glcp-(4←1)-α-L-Rhap
Cauloside G	β-D-Glcp-(1→2)-α-L-Arap–	–β-D-Glcp-(6←1)-β-D-Glcp-(4←1)-α-L-Rhap

There were investigated effects of triterpene glycosides of hederagenin – caulosides A, C, D and G (Table 2), derived from *Caulophyllum robustum* Maxim. upon root growth of seedlings *Cucumis sativus* L. Caulosides A and C have one carbohydrate chain. These compounds have inhibitory effect upon the growth of seedlings roots of *C. sativus* (10.3 and 20.4% respectively) at concentrations of 500 and 100 µg/ml. Caulosides D and G have two carbohydrate chains. These compounds have not inhibitory effect upon the growth of seedlings roots of *C. sativus* at a concentration of 500 µg/ml. Caulosides D and G have weak stimulant effect at concentrations of 100 (9.1%) and 250 (10.4%) µg/ml respectively. Inhibitory effect of Caulosides C (3) first is directed to the seedlings with intensively growing main root (Anisimov, Chaikina, in press).

5.4 Glycosides of Sea Cucumbers

Representatives of class of sea cucumbers (class Holothurioidea, type Echinodermata) are widely distributed throughout the world's Oceans. More than 70 species of sea cucumbers, mostly tropical, are used as food and in traditional oriental medicine. *Cucumaria japonica* and *Cucumaria frondosa* are among the largest and mass species of sea cucumbers and are the objects of fishing in our country (Levin & Gudimova, 1997). The study showed that triterpene glycosides of the Far Eastern edible holothurian *Cucumaria japonica* (monosulfated glycosides of groups A_2 and A_4, disulfated subfraction A_6, trisulfated subtraction A_7, and the total fraction of monosulfated glycosides including subtractions A_0, A_1, A_2, and A_4) inhibit growth of the main root of *C. sativus* seedlings. Cucumariosides are arranged as follows according to their inhibitory activity: subfraction A_2 (ED_{50} 53.1 µg/ml) > total fraction of monosulfated glycosides (ED_{50} 127.4 µg/ml) > subfraction A_4 (ED_{50} 346.5 µg/ml) > subfraction A_6 (ED_{50} 375.7 µg/ml) > subfraction A_7 (ED_{50} 539.4 µg/ml). It was defined that when glycosides concentration in the medium increases, so the average length of the main root of seedlings decreased due to increase of seedlings number with low growth ability and absolute absence of seedlings with high growth ability (Anisimov et al., 2004).

6. Glycosides of Starfish

Starfish (Echinoderms species) are characterized by a large variety of high oxidated steroid compounds. The article presents data on the effect of steroid glycosides 1–3 (Figure 6), derived from the starfish *Asteropsis carinifera*, upon the growth of seedlings roots and stems of *G. max, F. esculentum, Z. mays* and *Orysa sativa*. Compound 1 showed stimulant effect on the growth of seedlings roots of *F. esculentum* by 17 and 13% (at a concentration of 10^{-5} и 10^{-2} µg/ml) and *Z. mays* – 11 and 13% (10^{-8} и 10^{-5} µg/ml), but did not show stimulant effect upon the growth of seedlings roots of *G. max* and *O. sativa*. Compound **2** showed a stimulant effect upon the growth of seedlings roots and sprouts of *G. max* by 15 and 11% (at a concentration of 10^{-1} µg/ml). This compound showed stimulant effect on the growth of the root of *O. sativa by* 13, 12 and 13% at a concentration of 10^{-8}, 10^{-4} and 10^{-1} µg/ml. Compound **3** showed significant stimulant effect upon the growth of seedlings root of O. sativa by 27% at a concentration of 10^{-3} µg/ml (Anisimov et al., 2012c).

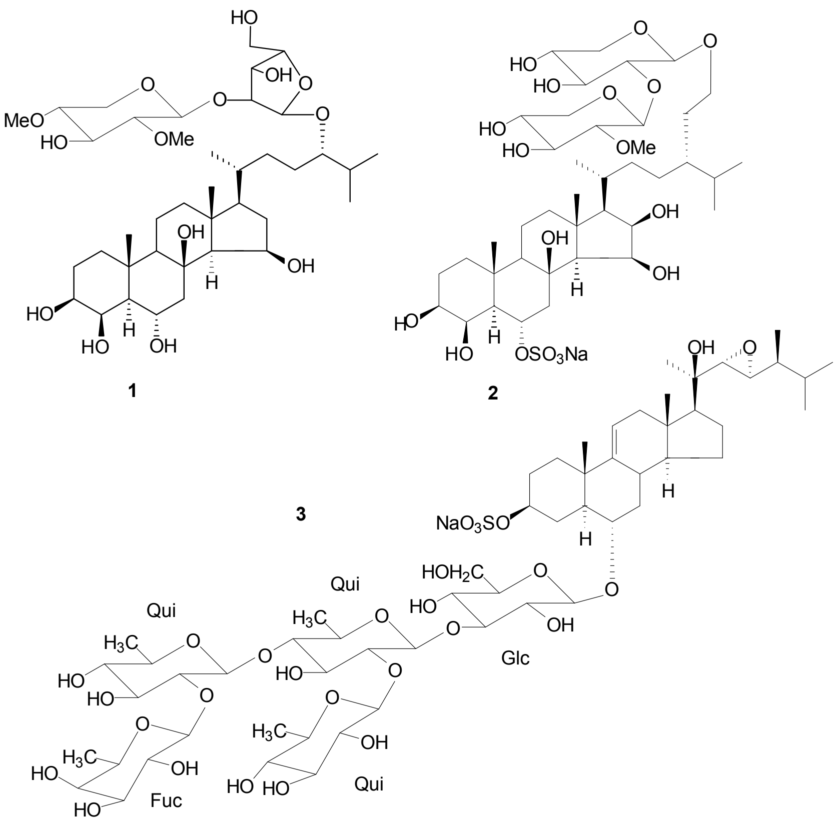
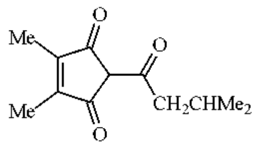


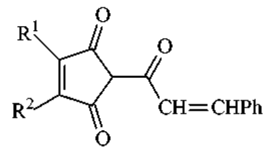
Figure 6. Chemical structure of steroid glycosides of starfish *Asteropsis carinifera*

7. *β,β′*-Triketones

At present time there are defined only four free triketones: kalitron (1) (Birch, 1951), linderon (2) (Kiang *et al.*, 1962), lutsidon (3) (Lee, 1968) and coruskanon B (4) (Facundo et al., 2004). These compounds and also their natural analogues 5–7 showed high biological activity (Aoyama et al., 2001). Here is presented data about effect of *β,β*'-triketones 4, 8–19 (Figure 7) upon the growth of seedlings root of *F. esculentum* and *Z. mays* The most active inhibiting effect upon growth of seedlings root of *F. esculentum* and *Z. mays* had substance 14. ED_{50} was equal 15.1×10^{-5} M.



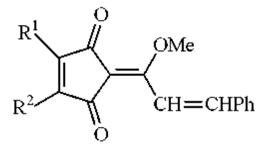
1



2 $R^1=R^2=OMe$

3 $R^1=OMe$, $R^2=H$

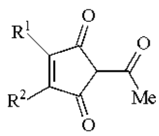
4 $R^1=Me$, $R^2=H$



5 $R^1=R^2=OMe$

6 $R^1=OMe$,$R^2=H$

7 $R^1=Me$, $R^2=H$



8 $R^1 = R^2 = H$

9 $R^1 = Me$, $R^2 = H$

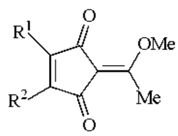
10 $R^1 = Cl$, $R^2 = H$

11 $R^1 = Br$, $R^2 = H$

12 $R^1 = R^2 = Me$

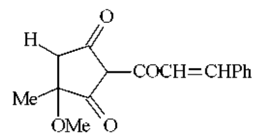
13 $R^1 = Cl$, $R^2 = Me$

14 $R^1 = R^2 = Cl$

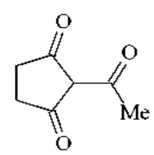


15 $R^1 = Me$, $R^2 = H$

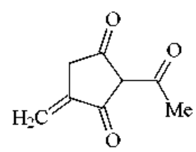
16 $R^1 = R^2 = Cl$



17



18

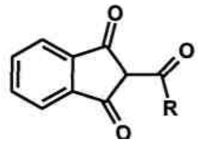


19

Figure 7. Chemical structure of *β,β'*-triketones

The least active was substance 18. ED_{50} was equal 64.5×10^{-5} M. Important role in the inhibitory action of *β,β'*-triketones plays a double relation at the position 4 (5). Removing it from the structure considerably reduces the activity of triketones: 8 (ED_{50} 44.2×10^{-5} M) > 18 (ED_{50} 64.5×10^{-5} M). The compounds decrease activity when double relation is displaced from the cycle of C-4 into the side chain: 9 (ЭД$_{50}$ 20.9×10^{-5} M) > 19 (ЭД$_{50}$ 50.3×10^{-5} M). Coruskanon (4) showed weaker inhibiting effect upon the growth of seedlings root of *F. esculentum*, than its analogue 9. Some *β,β'*- triketones showed stimulant effect on the growth of seedlings root of *F. esculentum.* Thus, compounds 4 and 8 showed stimulant effect by 12 and 20%, respectively at a concentration of 0.1 µg/ml (Demina et al., 2008; Shestak et al., 2010).

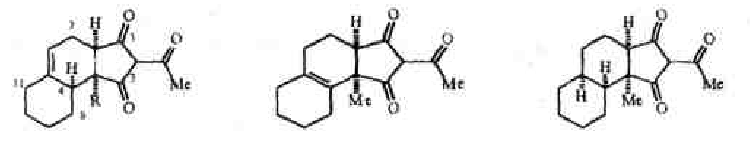
Cyclopentane *β,β'*-triketones of indane series (compounds 20–25) (Figure 8) also have inhibiting effect upon the growth of seedlings roots of *F. esculentum* at a concentration of 10–100 µg/ml. The least active inhibitors were compounds wherein R = H (**20**) and R = OMe (**25**).



20 R = H, **21** R = Me, **22** R= Et, **23** R = i-Pr, **24** R = t-Bu, **25** R = OMe

Figure 8. Chemical structure of cyclopentane *β,β'*-triketones of indane series

The most active inhibitor of the growth was substance 24, with the most branched hydrocarbon radical R, which inhibited the growth of seedling roots of buckwheat by 72% at a concentration of 10 µg/ml (Demina et al., 2006a). Effect of tricyclic syn-cis-*β,β′*-triketones 26–29 (Figure 9) upon the growth of seedlings roots of *F. esculentum* was also studied. The least active inhibiting effect upon the growth of root of *F. esculentum* had tricyclic syn-cis-*β,β′*-triketone 26 (ED_{50} 75.0 µg/ml) in comparison with triketones 27–29. More significant effect upon the biological activity of the compounds of this group has the presence or absence of a double relation in the six-membered ring of B group: triketone 29 showed the highest activity (ED_{50} 21.0 µg/ml) (Demina et al., 2006b).



26 R = H; **27** R = Me **28** **29**

Figure 9. Chemical structure of tricyclic syn-cis-*β,β′*-triketones

Thus, for the first time it is shown that *β,β′*-triketones have growth-regulatory activity in relation to seedlings root of *F. esculentum, Z. mays* and *C. sativus* (Novikov et al., 2003; Demina et al., 2008; Shestak et al., 2010). It was defined that the structural features of *β,β′*-triketones largely determine level of their growth-regulatory action.

8. Conclusion

Thus, some of the studied metabolites derived from terrestrial plants and marine organisms in the Russian Far East, as well as drugs, synthesized on their basis are worthy to notice as regulators of growth of agricultural plants. Compounds causing significant growth inhibition of plants are prospective for study as herbicides. Their introduction into practice will increase plant productivity, and hence the profitability of crop production.

References

Afiyatullov, Sh. Sh., Chaikina, E. L., Kraskovskaya, N. A., & Anisimov, M. M. (2012). Effect of Alkaloids from the Marine-derived Strain of the Fungus *Aspergillus fumigatus* Fresen. on the Root Growth of Corn (*Zea mays* L.) Seedlings. *Agrokhimiia, 7*, 39-42.

Ahmed, Y. M., & Shalaby, E. A. (2012). Effect of Different Seaweed Extracts and Compost on Vegetative Growth, Yield and Fruit Quality of Cucumber. *Journal of Horticultural Science & Ornamental Plants, 4*, 235-240.

Anisimov, M. M., & Chaikina, E. L. (2014a). Effect of Seaweed Extracts on the Growth of Seedling Roots of Soybean (*Glycine max* (L.) Merr.). Seasonal Changes in the Activity. *International Journal of Current Research and Academic Review, 2*(3), 19-23.

Anisimov, M. M., & Chaikina, E. L. (2014b). The Influence Glycosides of Hederagenin from the *Caulophyllum robustum* Maxim. on the growth of seedling roots of *Cucumis sativus* L. *Khimiia rastitel'nogo syr'ia (Chemistry of plant raw material)*. Accepted for publication.

Anisimov, M. M., Chaikina, E. L., Afiyatullov, Sh. Sh., & Klykov, A. G. (2012b). Influence Alkaloids from the Marine-Derived Strain of the Fungus *Aspergillus fumigatus* Fresen. on the Growth of Seedling Roots of Buckwheat (*Fagopyrum esculentum* Moench). *International Journal of Research and Reviews in Applied Sciences, 13*(1), 326-329.

Anisimov, M. M., Chaikina, E. L., Afiyatullov, Sh. Sh., & Vashchenko, A. P. (2013b). Influence of Alkaloids from the Marine_Derived Strain of *Aspergillus fumigatus* on the Root Growth in Soybean (*Glycine max* (L.) Merr.) Seedlings. *Russian Agricultural Sciences, 39*(2), 102-104. http://dx.doi.org/10.3103/S106836741302002X

Anisimov, M. M., Chaikina, E. L., Afiyatullov, Sh. Sh., Zhuravleva, O. I., Klykov, A. G., Kraskovskaja, N. A., & Aminin, D. L. (2012a). Decumbenones A–C from Marine Fungus *Aspergillus sulphureus* as Stimulators of the Initial Stages of Development of Agricultural Plants. *Agricultural Sciences, 3*(8), 1019-1022. http://dx.doi.org/10.4236/as.2012.38123

Anisimov, M. M., Chaikina, E. L., Afyatullov, Sh. Sh., & Kuznetsova, T. A. (2010b). Effect of Diterpene Glycosides from the Fungus *Acremonium striatisporum* on the Root Growth of Corn (*Zea mays* L.)

Seedlings. *Agrokhimiia, 5*, 34-38.

Anisimov, M. M., Chaikina, E. L., Klykov, A. G., & Rasskazov, V. A. (2013a). Effect of Seaweeds Extracts on the Growth of Seedling Roots of Buckwheat (*Fagopyrum esculentum* Moench) is depended on the Season of Algae Collection. *Agriculture Science Developments, 2*(8), 67-75.

Anisimov, M. M., Chaikina, E. L., Malyarenko, T. V., Kicha, A. A., & Ivanchina, N. V. (2012c). Efficiency of the Steroid Glycosider from the Starfish *Asteropsis carinifera* and Heteroauxin to an Increase in the Sprouts of the Agricultural Plants. *Agrokhimiia, 3*, 41-47.

Anisimov, M. M., Gerasimenko, N. I., Chaikina, E. L., & Serebryakov, Yu. M. (2009). Biological Activity of Metabolites of the Herb *Kalanchoe diagremontania* (Hamet de la Bathie) Jacobs et Perr. *Biology Bulletin, 36*(6), 568-574. http://dx.doi.org/10.1134/S1062359009060041

Anisimov, M. M., Logachev, V. V., Demina, E. A., Komandrova, N. A., & Tomshich, S. V. (2005). Effect of plant polysaccharides on the growth of seedlings root of *Cucumis sativus* L. Paper presented at the *All-Russian Conference: New advances in chemistry and chemical engineering plant materials* (pp. 321-324). Barnaul. Book 1.

Anisimov, M. M., Logachev, V. V., Demina, E. A., Samoshina, N. F., Denisenko, M. V., & Uvarova, N. I. (2006). Structural and functional properties of lupane series triterpenoids. 4. Betulin and its structural analogues influence on *Cucumis sativus* L. (*Cucurbitaceae*) seedling root growth. *Rastitel'nye Resursy, 42*(3), 74-81.

Anisimov, M. M., Logachev, V. V., Likhatskaya, G. N., Makhan'kov, V. V., & Uvarova, N. I. (2003). Effect of Extractive Substances and Total Glycoside Fraction from *Panax ginseng* C. A. Meyer on Root Growth of *Cucumis sativus* L. Seedlings. *Biology Bulletin, 30*(3), 287-290. http://dx.doi.org/10.1023/A:1023868014868

Anisimov, M. M., Logachev, V. V., Sil'chenko, A. S., & Avilov, S. A. (2004). Influence of Triterpene Glycosides of the Holothurian *Cucumaria Japonica* on Root Growth in *Cucumis sativus* L. Seedlings. *Biology Bulletin, 31*(4), 416-422. http://dx.doi.org/10.1023/B:BIBU.0000036947.25869.a8

Anisimov, M. M., Martyys, E. A., Chaikina, E. L., & Gerasimenko, N. I. (2010a). Antimicrobial, hemolytic and plant growth regulator activity of extracts lipid from seaweed. *Khimija rastitel'nogo syr'ia (Chemistry of plant raw material), 4*, 125-130.

Anisimov, M. M., Petrova, O. M., Logachev, V. V., Donets, E. A., & Gorovoi, P. G. (2000b). Effect of Water–Ethanol Extract of Far-Eastern Relict Plant *Caulophyllum robustum* Maxim. on Root Growth of *Cucumis sativus* L. Seedlings. *Rastitel'nye Resursy, 36*(4), 100-104.

Anisimov, M. M., Stekhova, S. I., & Pokhilo, N. D. (1998). Effect of Betulafolientetraol on Root Growth of *Cucumis sativus* L. Seedlings. *Rastitel'nye Resursy, 34*(3), 103-106.

Anisimov, M. M., Strigina, L. I., Gorovoi, P. G., Aminin, D. L., & Agafonova, I. G. (2000a). Chemical Composition and Medico-Biological Properties of Triterpenoid Glycosides of the Far-East Plant *Caulophyllum robustum* (Family Berberidacae). *Rastitel'nye Resursy, 36*(1), 107-129.

Aoyama, Y., Konoike, T., Kanda, A., Naya, N., & Nakajima, M. (2001). Total synthesis of human chimase inhibitor methyllinderone and structure – activity relationships of its derivatives. *Bioorganic & Medicinal Chemistry Letters, 11*(13), 1695-1697. http://dx.doi.org/10.1016/S0960-894X(01)00265-7

Bhadury, P., Mohammad, B. T., & Wright, P. C. (2006). The current status of natural products from marine fungi and their potential as anti-infective agents. *Journal of Industrial Microbiology and Biotechnology, 33*(5), 325-337. http://dx.doi.org/10.1007/s10295-005-0070-3

Birch, A. J. (1951). β-Triketones. Part 1. The structures of angustione, dehydroangustione, calythrone, and flavaspidic acid. *Journal of the Chemical Society, 11*, 3026-3030. http://dx.doi.org/10.1039/JR9510003026

Chaikina, E. L., Gerasimenko, N. I., Klykov, A. G., & Anisimov, M. M. (2011). Effect of Extractive Substances of the Brown Alga *Laminaria cichorioides* Miyabe on the Growth of Sprouts and the Yield of Buckwheat. *Agrokhimiia, 3*, 51-55.

Chaikina, E. L., Shevchenko, N. M., Zvyagintseva, T. N., & Anisimov, M. M. (2009). Influence of Polysacharides from Brown Algae on Seed Germination and Seedling Growth of *Glycine max (*Fabaceae*)* and *Fagopyrum esculentum* (*Polygonaceae*). *Rastitel'nye Resursy, 45*(3), 130-136.

Costa, S. S., Souza, M. L. M., Ibrahim, T., Melo, G. O., Almeida, A. P., Guette, C., … Koatz, V. L. G. (2006). *Kalanchosine dimalate*, an Anti-inflammatory Salt from *Kalanchoe brasiliensis*. *Journal of Natural*

Products, 69(5), 815-818. http://dx.doi.org/10.1021/np050475+

Craigie, J. S. (2011). Seaweed extract stimuli in plant science and agriculture. *Journal of Applied Phycology, 23*, 371-393. http://dx.doi.org/10.1007/s10811-010-9560-4

Da-Silva, S. A. G., Costa, S. S., & Rossi-Bergmann, B. (1999). The anti-leishmanial effect of Kalanchoe is mediated by nitric oxide intermediates. *Parasitology, 118*, 575-582. http://dx.doi.org/10.1017/S0031182099004357

Da-Silva, S. A. G., Costa, S. S., Mendonca, S. C. F. Silva, E. M., Moraes, V. L. G., & Rossi-Bergmann, B. (1995). Therapeutic effect of oral *Kalanchoe pinnata* leaf extract in murine leishmaniasis. *Acta Tropica, 60*, 201-210. http://dx.doi.org/10.1016/0001-706X(95)00128-2

Debbab, A., Aly, A. H., Lin, W. H., & Proksch, P. (2010). Bioactive compounds from marine bacteria and fungi. *Microbial Biotechnology, 3*, 544-563. http://dx.doi.org/10.1111/j.1751-7915.2010.00179.x

Demina, E. A., Fedorova, V. Ya., Shestak, O. P., Novikov, V. L., & Anisimov, M. M. (2006b). Tricyclic cyclopentane β,β'-triketones – reversible inhibitors of seedling growth of crops. *Khimiya i tekhnologiya rastitel'nykh veshchestv (Chemistry and Technology of Plant Compounds)* (p. 243). Abstracts of Papers, IV Vseross. konf. (IV All-Russia Conf.), Syktyvkar.

Demina, E. A., Shestak, O. P., Novikov, V. L, & Anisimov, M. M. (2008). Growth-regulatory action of natural and synthetic 2-acylcyklopent-4-ene-1,3-diones and their derivatives on the seedlings *Fagopyrum esculentum. Khimiia rastitel'nogo syr'ia (Chemistry of plant raw material), 3*, 107-110.

Demina, E. A., Shestak, O. P., Novikov, V. L., & Anisimov, M. M. (2006a). Growth-regulatory effect of 2 acylindan-1,3-diones on seedlings Fagopyrum esculentum Moench. Paper presented at the II Regional Conference "Research on Physico-Chemical Biology and Biotechnology". *PIBOC FEB RAS* (p. 13).

Facundo, V. A., Sa, A. L., Morais, S. M., Matos, C. R. R., & Braz-Filho, R. (2004). Three new natural cyclopentenediones derivatives from *Piper carniconnectivum*. *Journal of the Brazilian Chemical Society, 15*(1), 140-145. http://dx.doi.org/10.1590/S0103-50532004000100022

Fedorova, V. Ya., Chaikina, E. L., Bakunina, I. Yu., Anastyuk, S. D., Isakov, V. V., Anisimov, M. M., & Zvyagintseva, T. N. (2010). Effect of 1,3;1,6-β-*D*-Glucan and the Products of Its Enzymatic Transformation on the Formation of Germs of Buckwheat *Fagopyrum esculentum* Moench. *Russian Journal of Bioorganic Chemistry, 36*(7), 934-940. http://dx.doi.org/10.1134/S106816201007023X

Gandhiyappan, K., & Perumal, P. (2001). Growth promoting effect of seaweed liquid fertilizer (Enteromorpha intestinalis) on the sesame crop plant. *Seaweed Research, 23*, 23-25.

Greve, H., Mohamed, I. E., Pontius, A., Kehraus, S., Gross, H., & Konig, G. M. (2010). Fungal metabolites: Structural diversity as incentive for anticancer drug development. *Phytochemistry Reviews, 9*, 537-545. http://dx.doi.org/10.1007/s11101-010-9198-5

Hong, D. D., Hien, H. M., & Son, P. N. (2007). Seaweeds from Vietnam used for functional food, medicine and biofertilizer. *Journal of Applied Phycology, 19*(6), 817-826. http://dx.doi.org/10.1007/s10811-007-9228-x

Imbs, T. I., Chaykina, E. L., Dega, L. A., Vashchenko, A. P., & Anisimov, M. M. (2011). Comparative Study of the Chemical Composition of Ethanol Extracts from Brown Algae and Their Effects on Seedling Growth and Productivity of Soya *Glycine max* (L.) Merr. *Russian Journal of Bioorganic Chemistry, 37*(7), 871-876. http://dx.doi.org/10.1134/S1068162011070090

Jayaraj, J., Wan, A., Rahman, M., & Punja, Z. K. (2008). Seaweed extracts reduces foliar fungal disease on carrot. *Crop Protection, 27*(10), 1360-1366. http://dx.doi.org/10.1016/j.cropro.2008.05.005

Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., … Prithiviraj, B. (2009). Seaweed extracts as biostimulants of plant growth and development. *Journal of Plant Growth Regulation, 28*(4), 386-399. http://dx.doi.org/10.1007/s00344-009-9103-x

Kiang, A. K., Lee, H. H., & Sim, K. Y. (1962). The structure of linderone and methyl-linderone. *Journal of the Chemical Society, 11*, 4338-4345. http://dx.doi.org/10.1039/JR9620004338

Klykov, A. G**.,** Anisimov, M. M., Moiseenko, L. M., Chaikina, E. L., & Parskaya, N. S. (2014). Effect of biologically active substances on morphological characteristics, rutin content and productivity of *Fagopyrum esculentum* Moench. *Agriculture Science Developments, 3*(1), 139-142.

Klykov, A. G., Moiseenko, L. M., Chaikina, E. L., Afiyatullov, Sh. Sh., & Anisimov, M. M. (2013a).

Productivity and Productivity and Quality of Seeds of *Fagopyrum esculentum* Moench under Treatment with Virescenosides A and a Sum of Glycosides of Marine Fungus *Acremonium striatisporum* at Super Low Concentrations. *Russian Agricultural Sciences, 39*(4), 303-306. http://dx.doi.org/10.3103/S1068367413040095

Klykov, A. G., Moiseyenko, L. M., & Anisimov, M. M. (2013b). Effect of biologically active substances on the growth of seedling roots and rutin content in *Fagopyrum esculentum* Moench. Paper presented at the 12th International symposium on buckwheat, Lasko, Slovenia, Aug. 21-25, 2013. *Proceedings of Papers* (pp. 165-166).

Kumari, R., Kaur, I., & Bhatnagar, A. K. (2011). Effect of aqueous extract of *Sargassum johnstonii* Setchel & Gardner on growth, yield and quality of *Lycopersicon esculentum* Mill. *Journal of Applied Phycology, 23*, 623-633. http://dx.doi.org/10.1007/s10811-011-9651-x

Lee, H. H. (1968). The structure of lucidone and methyl-lucidone. *Tetrahedron Letters, 9*(40), 4243-4246. http://dx.doi.org/10.1016/S0040-4039(00)76397-0

Levin, V. S., & Gudimova, E. N. (1997). Taxonomic interrelations of holothurians *Cucumaria frondosa* and *C. japonica* (*Dendrochirotida*, *Cucumariidae*). *Zoologicheskii zhurnal, 76*(5), 575-584.

Misra, S. B., & Dixit, S. N. (1979). Antifungal activity of leaf extracts of some higher plants. *Acta Botanica Indica, 7*, 147-150.

Moraes, V. L. G., Santos, L. F. M., Castro, S. B., Loureiro, L. H., Lima, O. A., Souza, M. L. M., … Costa, S. S. (1994). Inhibition of lymphocyte activation by extracts and fractions of Kalanchoe, Alternanthera, Paullinia and Mikania species. *Phytomedicine, 1*, 199-204. http://dx.doi.org/10.1016/S0944-7113(11)80065-6

Nassis, C. Z., Haebisch, E. M. A. B., & Giesbrecht, A. M. (1992). Antihistamine activity of *Bryophillum calycinum.* Brazilian Journal *of Medical and Biological Research, 25*(9), 929-936.

Novikov, V. L., Shestak, O. P., Logachev, V. V., & Anisimov, M. M. (2003). Influence of Some Synthetic Analogues of Nature (Cyclopentene) β,β′-Triketones on Growth of Seedlings Root (Taking *Cucumis sativus* L. as an Example). *Rastitel'nye Resursy, 39*(4), 87-94.

Pohilo, N. D., & Uvarova, N. I. (1988). Isoprenoids Various Species of the Genus Betula. *Chemistry of natural compounds, 3*, 325-341.

Proksch, P., Putz, A., Ortlepp, S., Kjer, J., & Bayer, M. (2010). Bioactive natural products from marine sponges and fungal endophytes. *Phytochemistry Reviews, 9*(4), 475-489. http://dx.doi.org/10.1007/s11101-010-9178-9

Rateb, M. E., & Ebel, R. (2011). Secondary metabolites of fungi from marine habitats. *Natural Product Reports, 28*, 290-344. http://dx.doi.org/10.1039/c0np00061b

Shestak, O. P., Chaikina, E. L., Novikov, V. L., & Anisimov, M. M. (2010). Influence of Cyclopentane β,β'-Triketones and Their Methyl Enol Ethers on the Growth of Seedling Roots of Zea mays L. *Khimiia rastitel'nogo syr'ia (Chemistry of plant raw material), 2*, 571-576.

Stekhova, S. I., Anisimov, M. M., Atopkina, L. N., & Uvarova, N. I. (2001). Structural and Functional Properties of Panaxosides of *Panax ginseng* C. A. Mey. and Similar Compounds. V. Influence of 20(S)-Protopanaxadiol and its Glycosides on Growth of the Root of Seedlings of *Cucumis sativus* L. *Rastitel'nye Resursy, 37*(1), 82-88.

Stekhova, S. I., Samoshina, N. F., Denisenko, M. V., Denisenko, V. A., Logachev, V. V., Anisimov, M. M., & Uvarova, N. I. (2002). Structural and Functional Properties of Lupane Triterpenes. I. Influence of Betulin Acid and 3-OGlycosides of Betulin and Dihydrobetulin Acids on Growth of the Root of Seedlings of *Cucumis sativus* L. *Rastitel'nye Resursy, 38*(2), 92-99.

Supratman, U., Fujita, T., Akiyama, K., & Hayashi, H. (2000). New insecticidal bufadienolide, bryophyllin C, from *Kalanchoe pinnata*. *Bioscience, Biotechnology, and Biochemistry, 64*(6), 1309-1311. http://dx.doi.org/10.1271/bbb.64.1310

Supratman, U., Fujita, T., Akiyama, K., & Hayashi, H. (2001). Insecticidal compounds from *Kalanchoe daigremontiana* x *tubiflora*. *Phytochemistry, 58*(2), 311-314. http://dx.doi.org/10.1016/S0031-9422(01)00199-6

Uvarova, N. I., Makhan'kov, V. V., Malinovskaya, G. V., Samoshina, N. F., Atopkina, L. N., Likhatskaya, G. N., … Elyakov, G. B. (2000). Chemical Properties, Comparative Analysis, and Biological Activity of

Triterpene Glycosides from Wild and Planted Ginseng *Panax ginseng* C.A. Meyer of Far East Origin. *Khimiko-Farmatsevticheskii Zhurnal, 34*(3), 19-25.

Yadav, N. P., & Dixit, V. K. (2003). Hepatoprotective activity of leaves of *Kalanchoe pinnata* Pers. *Journal of Ethnopharmacology, 86*(2-3), 197-202. http://dx.doi.org/10.1016/S0378-8741(03)00074-6

Yurchenko, A. N., Smetanina, O. F., Khudyakova, Y. V., Kirichuk, N. N., Chaikina, E. L., Anisimov, M. M., & Afiyatullov, S. S. (2013). New oxirapentyn E from marine isolate of the fungus *Isaria felina*. *Chemistry of Natural Compounds, 49*, 857-860. http://dx.doi.org/10.1007/s10600-013-0764-0

Zaostrovnyh, V. I., Simkina, T. F., Shevchenko, N. M., Chaikina, E. L., Zvyagintseva, T. N., & Anisimov, M. M. (2010). Use of Carbohydrate Containing Biopolymers from Brown Seaweed on Growth, Efficiency and Stability to Diseases. *Dostizeniy nauki i tehniki APK, 5*, 42-43.

Zhang, X. Z., & Ervin, E. H. (2004). Cytokinin–containing seaweed and humic acid extracts associated with creeping bentgrass leaf cytokinins and drought resistance. *Crop Science, 44*(5), 1737-1745. http://dx.doi.org/10.2135/cropsci2004.1737

Zhang, X., & Ervin, E. H. (2008). Impact of seaweed extract-based cytokinins and zeatin riboside on creeping bentgrass heat tolerance. *Crop Science, 48*(1), 364-370. http://dx.doi.org/10.2135/cropsci2007.0.5.0262

Zodape, S. T., Kawarkhe, V. J., Patolia, J. S., & Warade, A. D. (2008). Effect of liquid seaweed fertilizer on yield and quality of okra (Abelmoschus esculentus L.). *Journal of Scientific and Industrial Research, 67*, 1115-1117.

Zvyagintseva, T. N., Sova, V. V., Bakunina, I. Yu., Sundukova, E. V., Shevchenko, N. M., Ermakova, S. P., & Elyakova, L. A. (1998). Marine organisms as a source of biologically active polysaccharides, polysaccharide hydrolases with unique specificity and their inhibitors. *Khiniia v interesah ustoichivogo razvitiia (Chemistry for Sustainable Development), 6*, 417-426.