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Research Article

Characterisation of biological properties of co-composted Baltic seaweeds in germination tests

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Large quantities of green seaweed, probably due to eutrophication, are found in the Baltic Sea, as well as on the beach. The tourist attractiveness of the seaside resorts is therefore reduced. The aim of this study was to find the method of the utilization of this algal biomass into fertilizers. Algae, collected from the Baltic Sea, were co-composted with sawdust and quail manure in order to produce natural fertilizer. From the compost, algal extract was additionally produced that can act as a plant growth biostimulant. The compost and extract were biologically evaluated by the determination of the growth and multielemental composition of garden cress (*Lepidium sativum*) in germination tests. Additionally, the odour emissions during composting process were investigated. It was found that the dry biomass was comparable in all examined groups (compost, extract, distilled water). The average length of plants in the group with compost was 14.5% higher than in the group with the extract (difference not statistically significant). There has been observed a positive effect of the addition of compost on the content of micro- and macronutrients in the biomass of the cultivated plants, especially boron, calcium, iron and silicon. The averaged odour concentrations measured from the compost and extract samples were very low and reached the values of 8 and 24 ou_E/m³, respectively. According to the obtained results, by composting of seaweeds it is possible to produce a valuable organic fertilizer, which is the method of valorisation of this biomass.

Keywords: Algal biomass / Biostimulant / Composting / Natural fertilizer / Odour control

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1 Introduction

In Poland, drifting algae or algae on the beach constitute a serious problem. According to the WAB Project (Wetlands Algae Bio-gas; <http://wabproject.pl>), only from the beach and sea in Sopot (Poland) in July, August and September 2011, almost 400 tons of algal biomass was collected — 164 tons from the beach and 231 tons from the water. The presence of so-called “green wave” leads to algae covering beaches, canals, reservoirs and can even cause limited access to ports. This reduces the tourist attractiveness [1]. The most abundantly available species of seaweeds reported at Baltic coast (Gulf of Gdańsk) are *Ulva* sp., *Cladophora* sp. and *Polysiphonia* sp. [2]. Not removing of beach debris (including

algal biomass, microbiota and animals) may result in their retention on the beaches and natural decomposition, which, in turn, may contribute to odour emissions. This is a problem because H₂S emissions are hazardous to people and environment [3].

One of the methods of utilisation of this algal biomass is to use it to fertilize the nearby land [4]. There is a long history of coastal people using seaweeds casted up by tides and storms as natural fertilizers [5]. Algae are known to be particularly rich in macro- (e.g. K) and microelements (e.g. B, I, Zn, Mn, Cu, Mo), amino acids, vitamins, as well as growth activators such as auxins, cytokinins and alginates, which improve the soil structure and plant growth development [5–10]. Algae have an effect on soil health (soil structure, moisture retention, growth of rhizosphere microbes, etc.), on plant growth and health (root development, mineral absorption, shoot growth and photosynthesis, vegetative propagation, crop yield, etc.), on resistance to environmental stresses (alleviation of biotic and abiotic stress) [7].

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Part of the drifting algae or cast beach algae can be composted and then used for plant cultivation. Composting can be treated as a method of utilisation of seaweeds to useful organic fertilizer [4, 11–13]. The produced compost can improve the soil value including a structure, a filtration quality, the enhancement of water retention ability, the aeration vulnerability, temperature stability, the completion of hummus. The fertilization of soils with a compost prevents them from wind and water erosion, which diminish a chance of pollution of ground and surface water [14, 15]. Compost provides also organic biomass and nutrients for plants. It reduces the risk of development of plant diseases [15]. However, in order to make the usage of compost beneficial, a special care should be put on its value. The potential problems in the compost application can entail: sanitary and epidemiological risk (large microbiological activity in raw compost), level of impurities (including heavy metals), weed seeds and odour emission. Owing to this fact, a compost should be fully stabilised, not limed and not causing odour emissions [1, 6, 16]. During composting of algae, organic compounds are decomposed. The relevant greenhouse gasses (CO_2 , CH_4 and N_2O) are produced in the composting processes [1]. Anaerobic digestion of the biomass can remove some of the organic matter and produce a biogas, mainly composed of CH_4 and CO_2 . Additionally, during natural anaerobic biodegradation of seaweeds rich in sulphur (e.g. green macroalgae — *Ulva* sp.) substantial amounts of gaseous sulphur compounds including hydrogen sulphide (H_2S), carbon disulphide and mercaptans (methyl sulphide and associates) are generated [17].

In the literature, there are some data on the co-composting of macroalgae collected in different parts of the world, for example seaweeds from Cape Monze and Manora (Karachi coast) [10], seaweed (mainly *Laminaria* spp. and *Cystoseira* spp.) from the northern coast of Galicia (Spain) [12, 13], *Ulva rigida* from the Venice Lagoon (Italy) [18], seaweed (mainly *Laminaria* spp. and *Cystoseira* spp.) from Foz (Spain) [11], *Ulva* sp. from the Hillion Bay area (Gulf of St Malo, Brittany, France) [19], seaweed *Ulva* sp. from Paracas Bay (Peru) [20]. In the Web of Knowledge database (13.01.2016), there is no scientific publications concerning the composting of algae from the Baltic Sea. The problem of odour emissions during co-composting process of seaweed biomass is also rarely studied (e.g. 10, 19, 20). In the Web of Knowledge database (13.01.2016), there is no paper that has in the topic keywords such as “seaweed compost” and “odour emissions”.

In this study, compost consisted of the algal biomass collected directly from the water in the coastal zone and of quail manure was produced. The obtained compost was characterised in terms of its multielemental composition, pH and odours emissions. From the compost, extract was produced by filtration. The same characteristics as for compost were provided for the extract. The utilitarian properties of the obtained product were examined in the germination tests on the garden cress (*Lepidium sativum*). The main objective of this study was to verify, which of the tested products better affected the growth of plants — compost treated as a natural fertilizer or extract treated as plant growth biostimulant. The obtained biomass of cultivated plants was examined in terms of the length, weight, multielemental composition and chlorophyll content.

Table 1. Changes in the ratio of carbon and nitrogen in the composted material

Component	C (% d.m.)	N (% d.m.)	Ratio C:N
Algae (30 kg d.m.)	19.7	1.64	12.0
Sawdust (14 kg d.m.)	50.2	0.18	279
Quail manure (1 kg f.m.)	33.0	7.65	4.3
Composting mixture (45 kg)	33.3	1.37	24.3

2 Materials and methods

2.1 Algal biomass

The drifting algal biomass (the mixture of *Cladophora* sp. and *Enteromorpha* sp.) was obtained from the Baltic Sea in the city of Sopot (Poland). The biomass was harvested in September 2013. Algae were collected mechanically directly from the water in the coastal zone, that allowed to minimise the contamination with sand. Immediately after harvesting, salt and sand were rinsed from the biomass. Then, contaminations such as stones, shells, wood, etc. were separated by the use of the perforated high-speed drums. The remaining sand fraction was sieved on a three-phase separator after the drying processes, which has been subjected to biomass. The reduction of humidity to 15% was carried out in two stages: in a warm press, where the by product was an algal filtrate rich in minerals, then co-drum dryer at a temperature < 55°C [21]. The prepared and purified Baltic algal biomass was subjected to composting process.

2.2 Composting process

On the basis of the analysis of the content of carbon and nitrogen in the mixture of seaweeds (*Cladophora* sp. and *Enteromorpha* sp.), sawdust and quail manure, the composting mixture was prepared. The ideal ratio of carbon and nitrogen for starting a composting process is C:N ratio of 22:1–40:1 [22]. In order to provide the proper C:N ratio, algal biomass was mixed with sawdust and quail manure. Such amendments are very often mixed with the primary material in order to balance the C:N ratio (increase carbon content), modify the pH, improve stability and achieve the proper moisture content [23]. The proper ratio of carbon to nitrogen in the composted material influences also the colonisation and activity of microorganisms responsible for composting process [1]. The values for the ingredients of the composting mixture, as well as during the process and in the final compost are presented in Table 1.

The initial composting mixture was composed of algae — 30 kg of dry mass (d.m.), sawdust — 14 kg d.m. and quail manure — 1 kg of fresh mass (f.m.) (humidity 40%). A total biomass — 45 kg was composted outdoor under atmospheric conditions in a composter EvoGREEN IKST (volume 600 L). The initial humidity of the compost mixture was approximately 60%. Compost was regularly thoroughly mixed in order to aerate and moisten the whole material. The composting process was conducted for

120 days. Measurement of humidity and temperature was carried out by the use of Temperature & Humidity meter logger NHR.

2.3 Evaluation of pH of the compost

The sample of air-dried compost was grounded in a mortar. In a beaker, 2 g of powdered compost were mixed with 25 mL of 0.1 M KCl. The content of the beaker was thoroughly mixed with a glass rod and left for 24 h. After this time, the content of the beaker was thoroughly mixed and the pH was measured using pH — meter Mettler-Toledo (Seven Multi; Greifensee, Switzerland) equipped with an electrode InLab413 [24].

2.4 Extract from the compost

From the obtained compost, extract was produced according to the procedure described by Alvarado et al.. Subsequently, 130 g of the compost was filtered using a funnel with filter paper and 300 mL of distilled water. The process was repeated 5 times. An intense brown colour liquid was obtained. The filtrate was considered as 100% [25].

2.5 Utilitarian properties of the compost and extract

The utilitarian properties of the obtained compost and extract were tested in the germination tests using garden cress (*Lepidium sativum*). Their purpose was to compare which tested product better affected the plant growth. They were carried out on plates (90 mm diameter) with wool (Lohmann & Rauscher company) in a germinator — type Jacobsen in the room temperature, according to the international norm (International Rules for Seed Testing, 2011 — International Seed Testing Association).

Fifty cress seeds were placed on each plate. Then, prepared plates were put for two days into a fridge (stratification process). Tests were performed in three variants: (1) a control sample ("0") — the growth of cress watered with distilled water (2 mL); (2) compost (C) — the growth of cress with addition of compost (0.5 g) and the watered with distilled water (2 mL) — Fig. 1(a); (3) extract obtained from the compost — 100% (E) — the growth of the cress watered with extract (2 mL) — Fig. 1(b). All the plates were watered with 2 mL of water every two days. Each group was performed in four replications. Germination tests lasted for 9 days. At the end of the experiment, the plants were collected from each plate, dried and the dry mass was weighed — $N = 4$ (four plates for each group; the average mass of 50 plants). The length of 20 randomly selected plants from each plate was measured ($N = 80$).

2.6 Analytical methods

The assay of the content of C and N was made with the CN analyser — Vario Macro Cube. The analysis of the elemental composition of the compost, extract, as well as the cultivated plants was performed using ICP-OES iCAP Axial and Radial

Vista in accordance with PN-EN ISO/IEC 17025:2005. Before multielemental analysis, the samples (0.5 g) underwent the mineralization (with 5 mL of 69% HNO_3) in Teflon bombs using the microwave oven — Milestone Start D.

The measurements of odour concentrations were made using four standing TO8 Ecoma olfactometer in accordance with PN-EN ISO/IEC 17025:2005 and PN-EN 13725:2007. The measurements were performed with the "yes – no" method. Odour concentration is expressed in European Odour Unit per cubic meter (ou_E/m^3). One European Odour Unit is equivalent to the amount of odourant, which is still sensed by half of the tested group, after evaporation in a volume of 1 m^3 of inert gas, at standard conditions. During selected dilution series, the evaluators alternately received clean, odourless air and an odourants samples collected from the surface of the compost and extract.

Chlorophyll content in the cultivated plants was measured with the use of spectrophotometric methods. The dry mass of *Lepidium sativum* ($N = 4$ from each group) was subjected to a methanolic extraction for 30 min. The obtained coloured solution was analysed by a UV-VIS spectrophotometer (Varian Cary 50 Conc. Instrument, Victoria, Australia), to determine the plant pigments. Measurements were made at wavelengths: $\lambda = 663, 645$ and 665 nm [26].

2.7 Statistical analysis

Obtained results were statistically elaborated using *Statistica 10* software. For all obtained results, the distribution was tested using normality test (Shapiro–Wilk). For normal distribution, homogeneity of variance was checked using Brown–Forsyth test. The differences between the groups were investigated with (RIR) Tukey test which compares all pairs of means following one-way ANOVA. Results were considered significantly different when $p < 0.05$ (confidence level is 95%).

3 Results and discussion

Algae have been used in agriculture for centuries. However, a significant salinity, presence of sand and the accumulation of heavy metals in algae significantly limits their direct use in the field fertilizing. Therefore, the solution can be the use of algal extract or compost [27], wherein the second method is much easier, involves lower costs and allows the utilisation of large quantities of biomass. Composting of algae may solve the problem of waste with regards to the environment, but also may improve the properties of soil. It should be also noted that the compost produced from algae has some advantages over conventional composts produced for example from plants or animal manure (see Table 2).

In the present paper, two products were obtained — compost and extract. The compost was proposed to be used as an organic fertilizer, whereas the extract as a plant growth biostimulant. Both products were examined in terms of their composition and utilitarian properties. Additionally, odour concentrations were evaluated.

Figure 1. Germination tests on *Lepidium sativum* in (A) a control group with water, (B) a group with extract from compost, (C) a group with compost, (A', B', C') germination of *Lepidium sativum* on the Petri dishes with germ cover domes in the appropriate tested groups.

3.1 Characteristics of the obtained products

3.1.1 C:N ratio in a mature compost

The ratio of carbon to nitrogen is an important parameter influencing the process of algae composting. It should be approximately 22–40 [22]. Generally, algal biomass has a relatively low C:N ratio, typically ranging from 8 to 11 [18, 19, 28]. The C:N ratio in the examined mixture of green macroalgae (12.0 — Table 1) was comparable to the results presented by other authors for green algae — *Ulva* sp.: 8.5 [19] and 8.75 [20]. Algae are characterised by a relatively low ratio of C:N, in addition to high

moisture [1]. An effective way to adjust the algal-based feedstock to have a suitable C:N ratio (around 22–40) is to mix with a high C:N ratio co-composting material. Sawdust, bark, straw and animal manure are commonly used as co-composting materials [1]. In this study, sawdust (as a rich source of carbon) and quail manure (as a source of nitrogen) were added to algae. Sawdust is characterised by very high C:N ratio — 279 in this study, when compared with other materials. Eyraş et al. reported that C:N ratio in sawdust — 208, is much higher than for algae [9].

Together with the process of composting, there was a change in a ratio of carbon to nitrogen in the composted material — it

Table 2. Benefits of algae compost over conventional compost

Benefits of algae compost over conventional compost	Ref.
Algal sludge treated as a novel organic fertilizer contained more nutrients, especially amino acids, than common mature chicken manure compost.	[46]
Higher abundance of protease-producing bacteria (responsible for the protein biodegradation) was observed during the composting process with algal sludge.	
The positive effect on heights, stem diameters and fresh biomasses of growing plants (cucumber, cayenne pepper, banana and maize).	[8]
Algal compost can be a richer source of biologically active compounds, for example: contains iodine, growth regulators, such as auxin — 5 times more than in the regular plant compost, cytokinins (adenine) — 5 times more, amino acids — 7 times more, additionally more Mn and Zn.	[9]
As raw materials for composting, seaweeds (e.g. <i>Ulva</i>) can contribute with microelements such as Zn, Mn, Cu and Mo in concentrations that are considered adequate for higher plants growth and development	[10]
Algal compost is a richer source of N, P, K (2.3, 0.86 and 1.8%, respectively) than commercially available Biogold organic compost (2.5, 0.32 and 0.87%, respectively)	[13]
The application of compost (from fish waste and seaweed) significantly increased the tomato yield and was associated with increased fruit weight and larger fruit diameter compared to crops receiving commercial organic fertilizer based on dried broiler litter. This could be due to the presence of other substances contained in the seaweed, such as growth regulators and alginates, which improve the physical, chemical and biological properties of soil.	

gradually decreased. The value of C:N in the mature compost should be below 20 [15]. Thus taking into account the final value of this parameter — 18.7 (after 120 days of composting), the compost can be considered as mature. The decrease in C:N ratio is caused by the transformation of organic carbon into carbon dioxide, followed by a reduction in the organic acid content [29]. During the composting process, which is essentially a biochemical process, C and N are mineralized and lost in gaseous forms as CO₂, NH₃, N₂O and N₂ [30].

3.1.2 Multielemental analysis of the components of compost, compost and extract

The obtained compost, consisting mainly of green macroalgae (*Cladophora* and *Enteromorpha*) — 67%, sawdust — 31% and quail manure — 2.0%, was examined in terms of its multielemental composition. The raw materials designated for the compost production were also examined. The results of the analysis are summarised in Table 3.

Algae were the main component of the composting mixture. They served as a rich source of microelements — mainly B, Cu, Fe, Mn, Ni and macroelements such as Mg and S. The next component of the obtained compost was quail manure, which was mainly the source of macroelements — Ca, K and P and microelements — Zn and Cu. However, this component constituted a small percent (2.0%) in the whole composting mixture. Therefore, algal biomass was a main source of the elements that were present in the initial composting mixture. Algal biomass (30 kg) contained 1209 g of Ca, 153 g of K, 35 g of P, 1.9 g of Zn and 0.38 g of Cu. The amounts of elements introduced to the composting mixture with quail manure (1 kg of fresh mass; 0.6 kg of dry mass) were much smaller: 30 g of Ca, 9.3 g of K, 7.8 g of P, 0.107 g of Zn and 0.010 g of Cu. Sawdust was poor in minerals — it was the main source of carbon. Similar results were also obtained in the work of López-Mosquera et al. who produced

the compost from seaweeds (*Laminaria* sp., *Cystoseira* sp.), fish waste and pine bark. Seaweeds provided mostly Mg and K, fish waste N, P and Ca, whereas bark represented a better source of carbon [11].

It was found that the content of toxic elements in the obtained compost was below the maximum acceptable levels: Cr (11.9 mg/kg d.m. < 100 mg/kg d.m. limits in the obligatory law), Cd (0.825 mg/kg d.m. < 5 mg/kg d.m.), Ni (4.88 mg/kg d.m. < 60 mg/kg d.m.), Pb (8.32 mg/kg d.m. < 140 mg/kg d.m.) taking into account Polish regulations [31].

The study showed the increase of the content of most elements in the mature compost in comparison with the starting material. In the case of microelements the highest increase was observed for Mo (increase ~5.8 times), Cu (~2.4 times), Zn (~2.1 times), Fe (by 68%), B (by 33%), Mn (by 19%), Ni (by 15%). Among the macronutrients, the content of Ca, P and Mg increased significantly, by 59, 26 and 13%, respectively. Similar results were obtained by Orquin et al., who found that the content of macronutrients in the original mixture (seagrass and seaweed mixed with municipal yard and landscape green waste) was relatively low, except for Ca. Initial P, K, Ca and Mg content was 560, 7100, 77 500 and 6200 mg/kg d.m., respectively. In the obtained compost, the content of these macroelements increased by 41, 17, 3.6 and 21% [32]. In the work of Michalak et al., it was shown that the content of elements in the final compost produced from seaweed *Fucus* sp., ecological hay, grass, sawdust and spent mushroom substrate increased significantly, when compared with the initial composting mixture (Ca ~ 2 times, Fe ~ 2.5 times, Zn by 77%, P by 60%, Mg 36%) [33]. This can be due to transformation of organic matter and thus changes in the contribution of the individual elements in compost weight and elution of some components during composting process. Changes of the content of elements (including toxic metals) in the composted mixture depend also on many factors, including the applied input material, its composition, as well as composting

Table 3. Elemental composition of the components of compost, the obtained compost and extract ($N=3$)

Element	Wavelength nm	Components of compost			Compost "C"				Extract "E"
		Algae	Sawdust	Quail manure	The beginning MEAN $\pm$ SD	Day 46	Day 102	The end Day 120	The end
					mg/kg d.m.				mg/L
Microelements	B 249.772	97.8 $\pm$ 14.7	< LOD	14.2 $\pm$ 2.1	54.8 $\pm$ 8.2	82.4 $\pm$ 12.4	81.8 $\pm$ 12.3	72.6 $\pm$ 10.9	5.32 $\pm$ 0.80
	Cu 267.716	12.7 $\pm$ 1.9	2.31 $\pm$ 0.35	16.6 $\pm$ 2.5	6.84 $\pm$ 1.03	15.9 $\pm$ 2.4	15.2 $\pm$ 2.3	16.5 $\pm$ 2.5	0.239 $\pm$ 0.036
	Fe 324.754	6661 $\pm$ 1332	17.2 $\pm$ 2.6	1164 $\pm$ 233	3088 $\pm$ 618	4631 $\pm$ 926	5514 $\pm$ 1103	5194 $\pm$ 1039	3.59 $\pm$ 0.54
	Mn 257.61	232 $\pm$ 35	86.4 $\pm$ 13.0	182 $\pm$ 27	89.6 $\pm$ 13.4	116 $\pm$ 17	110 $\pm$ 16	107 $\pm$ 16	6.60 $\pm$ 0.99
	Mo 202.032	0.312 $\pm$ 0.047	< LOD	4.11 $\pm$ 0.62	0.406 $\pm$ 0.061	4.44 $\pm$ 0.67	0.397 $\pm$ 0.060	2.34 $\pm$ 0.35	0.167 $\pm$ 0.025
	Ni 231.604	5.23 $\pm$ 0.78	0.284 $\pm$ 0.042	2.93 $\pm$ 0.44	4.25 $\pm$ 0.55	2.79 $\pm$ 0.36	4.79 $\pm$ 0.62	4.88 $\pm$ 0.63	0.0273 $\pm$ 0.0055
	Zn 213.857	64.9 $\pm$ 9.7	10.1 $\pm$ 1.5	179 $\pm$ 27	37.2 $\pm$ 5.6	66.6 $\pm$ 9.9	70.2 $\pm$ 10.5	78.4 $\pm$ 11.8	0.507 $\pm$ 0.076
Macroelements	Ca 315.887	40292 $\pm$ 8058	2005 $\pm$ 401	49515 $\pm$ 9903	6656 $\pm$ 1331	12751 $\pm$ 2550	11421 $\pm$ 2284	10565 $\pm$ 2113	1317 $\pm$ 263
	K 766.491	5082 $\pm$ 1016	305 $\pm$ 46	15499 $\pm$ 3100	2702 $\pm$ 540	4298 $\pm$ 860	2711 $\pm$ 542	2272 $\pm$ 454	1516 $\pm$ 303
	Mg 285.213	3181 $\pm$ 636	570 $\pm$ 86	2676 $\pm$ 535	1887 $\pm$ 377	4284 $\pm$ 857	2340 $\pm$ 468	2138 $\pm$ 428	746 $\pm$ 112
	P 213.618	1155 $\pm$ 231	44.2 $\pm$ 6.6	13008 $\pm$ 2602	896 $\pm$ 134	1137 $\pm$ 227	1135 $\pm$ 227	1127 $\pm$ 169	15.0 $\pm$ 0.1
	S 181.972	8614 $\pm$ 1723	96.4 $\pm$ 14.5	3061 $\pm$ 612	4033 $\pm$ 807	4746 $\pm$ 949	4304 $\pm$ 861	3824 $\pm$ 765	1626 $\pm$ 325
Toxic elemnt	Cd 228.802	0.707 $\pm$ 0.093	0.382 $\pm$ 0.050	0.111 $\pm$ 0.014	0.418 $\pm$ 0.054	0.161 $\pm$ 0.021	0.608 $\pm$ 0.079	0.825 $\pm$ 0.107	0.0281 $\pm$ 0.0056
	Cr 267.716	9.60 $\pm$ 1.25	0.182 $\pm$ 0.024	4.37 $\pm$ 0.57	10.2 $\pm$ 1.3	6.06 $\pm$ 0.79	12.0 $\pm$ 1.6	11.9 $\pm$ 1.6	0.098 $\pm$ 0.020
	Pb 220.353	7.03 $\pm$ 0.91	0.377 $\pm$ 0.057	1.53 $\pm$ 0.20	3.67 $\pm$ 0.48	17.1 $\pm$ 2.2	6.98 $\pm$ 0.91	8.32 $\pm$ 1.08	< LOD
	Other elements								
Other elements	Al 308.215	1572 $\pm$ 314	20.1 $\pm$ 3.0	424 $\pm$ 64	694 $\pm$ 104	1884 $\pm$ 377	2059 $\pm$ 412	2444 $\pm$ 489	0.590 $\pm$ 0.089
	Co 228.615	2.84 $\pm$ 0.43	< LOD	< LOD	0.0767 $\pm$ 0.0192	1.53 $\pm$ 0.23	2.06 $\pm$ 0.309	3.85 $\pm$ 0.58	0.0785 $\pm$ 0.0196
	Na 588.995	6354 $\pm$ 1271	858 $\pm$ 129	3167 $\pm$ 633	6354 $\pm$ 1271	4707 $\pm$ 941	2578 $\pm$ 516	1935 $\pm$ 387	1573 $\pm$ 315
	Si 251.611	907 $\pm$ 136	64.5 $\pm$ 9.7	587 $\pm$ 88	1443 $\pm$ 289	110 $\pm$ 16	124 $\pm$ 19	1013 $\pm$ 203	19.5 $\pm$ 2.9

* <LOD: below the limit of detection.

conditions [34]. According to Faridullah et al., such an increase of micro- and macroelements might be due to the concentration effect as compost volume decreased with time [35].

The obtained final compost provided rich composition of micro- and macronutrients, particularly important for plant growth: P (0.113%), K (0.227%), Ca (1.06%), Mg (0.214%), S (0.382%), Fe (0.519%) and Na (0.193%). These values are similar to the ranges presented in the work of Michalak and Chojnacka (2013) for the composts produced from different species of seaweeds, for example: P 0.079–0.63%, K 0.37–9.05%, Na 0.31–1.9%, Ca 0.44–14.4%, Mg 0.26–2.52% [6]. Also the presence of nutritive elements in compost, such as micronutrients (Fe — 5194 mg/kg, Zn — 78.4 mg/kg, B — 72.6 mg/kg, Cu — 16.5 mg/kg, Mo — 2.34 mg/kg, Mn — 107 mg/kg) is essential for the development and growth of plants [24]. The algal compost may thus constitute a competitive material to other components of organic fertilizers used in the agriculture because it contains more micro- and macronutrients than, for example popularly used peat and is characterised by greater stability in the soil than fresh manure [15].

In this study it was also shown that the extract obtained from the compost was a rich source of micro- (Co, Cu, Mn, Mo, Zn) and macroelements, especially when compared with other extracts obtained from Baltic macroalgae by the acidic extraction [36] and microwave assisted extraction [26]. Major differences were observed in the macroelemental composition. For example, the content of Ca in the extract from compost was about 6 times higher than for extract obtained from the same algae by acidic extraction, K about 11 times higher, Mg about 26 times higher, P about 1.5 times higher and S about 3 times higher. However, it should be taken into account that the extract obtained from algae by traditional extraction techniques will have a constant composition, whereas it can be variable

for the extracts from compost, especially when algal compost is produced in outdoor conditions. Extract obtained from algal compost can be used as a plant growth biostimulant. In the literature it was shown that their positive effect on plants is due to the presence of microelements and plant growth regulators. Algal extracts enhances the germination of seeds, gives the resistance to the biotic (e.g. fungal diseases) and abiotic stress (e.g. drought, frost), increases uptake of plant nutrients [37].

3.1.3 pH of the compost

The average pH measurements obtained for the compost and its extract were equal to 6.49 and 6.59 ($N = 2$), respectively. The obtained results allow for the conclusion that the products can be safely used without the risk of acidification of the substrate. The value of pH of 7.0 is typical for compost with algae [9]. Similar values were noted for other compost containing algae produced from green macroalgae, for example ~ 7 [9], 7.5 [20,38], 6.8 [18].

3.1.4 Odour concentrations

The results of the measurements of odour concentrations for the compost and extract are given in Table 4. The average odour concentration of the sample of compost was 8 ou_E/m³, whereas the sample of the extract obtained from compost was 24 ou_E/m³.

The measured odour concentrations was on the low level. Additionally, odour quality (expressed as hedonic tone and character of the smell) from compost is characterise as "nice" or "neutral" smell, and the "smell of the forest" or "damp earth" [39] that may indicate no odour nuisance from compost. Emissions of odorous substances from agricultural activities are mainly related to the storage and use of natural fertilizers. Typically, an analysis of the composition of the exhaust gases is carried out

Table 4. Results of odour concentrations

The source of sample	Name of the sample	Odour concentration, ou _E /m ³	Average odour concentration, ou _E /m ³
Compost "C"	Compost/algae/1	13	8
	Compost/algae/2	0	
	Compost/algae/3	11	
Extract "E"	Compost/algae/extract/1	24	24
	Compost/algae/extract/2	24	
	Compost/algae/extract/3	24	

1 ou_E/m³ — The concentration at which an odour is detectable by a panel of selected human "sniffers" defined as the detection threshold and as an odour concentration of 1 European odour unit per cubic meter

but that type of analysis does not reflect the real odour impact as odour mixture. The results of olfactometric measurements of gases emitted from fertilizers on the basis of pig manure with different additives showed an odour concentration at a level of a few to a few hundred odour units per cubic meter [40]. In the case of compost, the most characteristic components of emitted pollutants are: hydrogen sulphide, mercaptans, aldehydes, geosmin and limonene. In the mature compost (stable), where there are no longer intensive microbial processes occurring, emission of odours into the atmosphere is limited. Substances that are responsible for the negative odourous impact have a low concentration in the ambient air, so it is difficult to identify and quantify them. Own study relating to odour concentrations determined by dynamic olfactometry in the gases emitted from the plant origin compost surface (green waste 20 02 1) showed odour concentrations at the detection limit level [41].

Uncontrolled, anaerobic biodegradation of algae can often be the source of the odours emission [1]. For this reason, properly designed and managed algal biomass composting can effectively prevent odour nuisance. Emissions of substances formed by algae decomposition, especially those with a high sulphur content, such as *Ulva* sp. (include hydrogen sulphide, carbon disulphide and mercaptans [17]) are not only a source of odours but also can pose a potential risk to human health during prolonged exposure through respiratory system or skin. The most important health effects include: irritation of the mucous membranes of the eyes and respiratory system, headaches, sleep and concentration disturbances [42].

3.2 Utilitarian properties of the obtained products

3.2.1 Germination tests on *Lepidium sativum*

The germination tests allowed to observe the positive effect of the compost and compost extract on the plant growth. Currently, the application of natural products such as algal extracts, having biostimulant character, is one of the element of agricultural production, which allows to limit the adverse impact of external factors such as frost or drought on crops and their

improvement [26, 38, 43]. Plant growth biostimulants enhance the synthesis of natural hormones, improve root growth and mineral uptake from the medium. In addition, they increase the resistance to adverse environmental conditions, such as drought, frost and cold, as well as stress related with the use of herbicides and the impact of environmental pollution. The use of biostimulants in the cultivation of plants increases yields and can help to improve the quality of crops [44, 45]. The parameters of organic fertilizers are regulated by the Regulation of the Minister of Agriculture and Rural Development dated 18 June 2008 on the implementation of certain provisions of the Act on fertilizers and fertilization (Dz. U. of 2008 No. 119, item. 765). In the case of biostimulants there is still a lack of appropriate regulations. The sector is still emerging and is still being defined. The lack of a regulatory framework makes it therefore difficult to collect reliable statistics. The definition of biostimulant products currently varies from one country to another, if there is even official recognition of the product category [45].

3.2.1.1 Height of the cultivated plants. From each plate ($N = 4$), 20 randomly selected plants were collected and measured. The results of measurements of the height of harvested plants in the following experiments were compared: ("0") — a control sample, (C) — a sample with the addition of compost from algae, (E) — a sample with an extract obtained from the produced compost. The greatest height of the grown plants was observed in the group containing compost (4.70 ± 0.53 cm; $N = 80$), then extract (4.02 ± 0.53 cm; $N = 80$) and finally control group (2.67 ± 0.76 cm; $N = 80$). The statistically significant differences were observed between the control group ("0") and the group with the addition of compost extract ($p = 0.006986$) and between the control ("0") and the group with the addition of the compost ($p = 0.000162$). The average length of plants in the group with compost was 14.5% higher than in the group with the extract (not statistically significant). In the previous paper, Michalak et al. examined the effect of compost and extract produced from the biomass of seaweeds *Fucus* sp. (2.5 kg dry mass (d.m.)), ecological hay (1 kg d.m.), grass (1 kg d.m.), sawdust (0.5 kg d.m.) and spent mushroom substrate (2.5 kg wet biomass (w.m.)) on the height of the cultivated *Lepidium sativum*. The average height (from four replicates) of plants fertilized with the compost (5.56 ± 0.11 cm) was higher than with the extract (5.45 ± 0.34 cm), but slightly (by 2.0%) [33].

Higher height of plants in experimental groups can result from the content of readily available nutrients essential for plant growth, in both the compost and the extract [38]. In the work of Huang et al., it was also observed that the compost produced from chicken manure with a certain amount of algae sludge (93:7 w/w) significantly enlarged the stem diameters and plant height of cucumber, cayenne pepper, banana and maize when compared to the control group — chicken manure compost [46].

3.2.1.2 Weight of the cultivated plants. The average dry weight of the plants — w (number of repetitions $N = 4$) from each group was as follows: for a control group $w("0") = 0.0567 \pm 0.0065$ g, for the group with the addition of compost $w(C) = 0.0521 \pm 0.0029$ g, for the group with the addition of the extract $w(E) = 0.0536 \pm 0.0008$ g. spr. The differences were not statistically significant.

In the work of Huang et al., it was found that the addition of compost that contained algae sludge significantly increased both the above- and belowground fresh biomass of the cultivated plants (cucumber, cayenne pepper, banana and maize). When compared with the control (chicken manure compost), the above-ground fresh biomasses increased by 53.5, 97.2, 177 and 142%, respectively [46]. Ahmed and Shalaby carried out study on the effect of different seaweed: red algae (*Asparagopsis* spp., *Gelidium pectinatum*) and green alga (*Enteromorpha intestinelis*) on plant vegetative growth of cucumber. The results showed that the appropriate dosage of extracts from red and green algae may improve vegetative growth and yield of cucumber plants. The use of these preparations increased the quantity of leaves, their surfaces and fresh and dry weight in comparison with the control plants supplied with the compost (organic manure) [43]. In the work of Abou El-Yazied et al., the results of an experiment conducted to investigate the effect of different doses of seaweed compost and various concentrations of seaweed extract on the growth of cultivars bean (*Phaseolus vulgaris* L.) were presented. The results indicate that the use of both, the compost and the algal extract, affected the rapid growth of plants, increasing the quantity and average size of leaves and stems and the fresh and dry weights of plants, when compared to the control [8]. Pise and Sable examined the effect of various seaweed extracts (*Ulva fasciata*, *Sargassum ilicifolium* and *Gracilaria corticata*) on growth and biochemical constituents of fenugreek (*Trigonella Foenum-graecum*) compared with the Hoagland nutrient medium. Shoot growth and fresh biomass were valued 50% higher when compared to the control. It has been found that the most effective extract was from *Ulva fasciata* [47]. Similar results were obtained by Shehata et al. studying the effect of seaweed extract on the growth of a celeriac plants cv. *Monarcha* in sandy soil. Plants sprayed with extracts were characterised by a higher rate of plant growth and fresh and dry weight of leaves when compared to the control [48]. In the experiment of Winberg et al., the effect of a mixture of compost (consisted of *Microdictyon umbilicatum*) on the growth of saltbush (*Rhagodia candolleana*) and coastal banksia (*Banksia integrifolia*) was investigated. Saltbush maintained enhanced growth rates for the 10 and 20% compost additions [49].

3.2.1.3 Multielemental composition of the cultivated plants. The results of the analyses of the elemental composition of grown plants are shown in Table 5.

There has been observed a positive effect of the addition of compost and extract on the content of micro- and macronutrients in the biomass of the cultivated plants — higher content of B, Fe, Mn, Zn, Ca, K, Mg, S, Na and Si has been obtained in comparison with the control sample. The compost better affected the growth and elemental composition of the plants when compared to the extract. Plants in this group contained high levels of nutrients essential for plants, for example: B ~ 8 times more than in the group with extract, Si ~ 2 times more, Ca by 41%, Fe by 36%, Cu by 26%, K by 15%. In the work of Michalak et al., it was shown that the compost produced from brown seaweed *Fucus* sp. (33.3%), ecological hay (13.3%), grass (13.3%), sawdust (6.7%) and spent mushroom substrate (33.3%) influenced mainly the content of microelements (B, Cu, Fe, Mn and Zn) and P in the cultivated *Lepidium sativum*, whereas the extract, the content

of macroelements (Ca, K, Mg and S) [33]. Sosnowski et al. has also confirmed that the application of the seaweed extract from *Ecklonia maxima* a field experiment increased P, K, Zn and Mn content in alfalfa aerial biomass [50]. Mininni et al. examined the possibility of the use of composts prepared by mixing seaweed — *Posidonia oceanica* at different rates (20% or 60%) with grapevine prunings and vegetable waste as partial substitutes for peat in the growing media used in the production of melon and tomato. The addition of 25% of the compost (containing 20% of algal residues — better option) to 75% of peat increased the content of Ca, Cu, Mn and Zn and decreased P and K in melon production. For the tomato, the increase was observed for K, Ca, Mg, Na, Fe, Mn and Zn and the decrease for P and Cu [22].

In the case of toxic metals, it was shown that some of them were transferred from the co-composted macroalgae to *Lepidium sativum*. The content of Cd in the examined compost was 0.825 mg/kg and in the extract 0.0281 mg/L, whereas in plants: 1.93 mg/kg and 1.52 mg/kg respectively. For Cr: compost 11.9 mg/kg (plant 4.61 mg/kg) and extract 0.098 mg/L (plant 5.26 mg/kg), for Pb: compost 8.32 mg/kg (plant < LLD mg/kg) and extract < LLD (plant < LLD). The main accumulation was observed for Cd. Similar results were obtained in the work of Greger et al. [51]. In the group with beach-cast algal compost, lettuce accumulated significantly more Cd in its edible parts while broad beans accumulated less Cd than the other crop species did (spinach, carrot, potato and red beet). Therefore, the transfer of heavy metals from composted macroalgae to crops depended also on plant species. Cd content in plants cultivated using seaweed compost exceeded EU limits [52]. High cadmium content is the reason for not growing edible plants in pure beach-cast algal compost. The introduction of co-composting materials can be a solution (the percent of algal biomass will be reduced). To avoid the Cd problem, it would be better to grow non-food crops in soil treated with macroalgal compost [51]. Castaldi et al., who studied the effect of composted and beached *Posidonia oceanica* on the growth and the transfer of toxic metals in the soil-plant system (lettuce — *Lactuca sativa* L.), concluded that most metals strongly interact with the organic matter of compost, limiting the vegetal absorption. The severity of pollution depends on the chemical form of the heavy metals, as well as soil type and plant species [53].

3.2.1.4 Content of chlorophyll in the cultivated plants. In this study, the highest content of total chlorophyll, Chl(a) and Chl(b) in *Lepidium sativum* was for the group with compost: Chl(a) 16.52 ± 0.03 ; Chl(b) 5.795 ± 0.021 ; total chlorophyll 22.32 ± 0.03 mg/L. The values for the extract and for the control group were as follows: Extract: Chl(a) 12.80 ± 0.02 ; Chl(b) 4.758 ± 0.475 ; total chlorophyll 17.29 ± 0.03 mg/L. Control: Chl(a) 12.86 ± 0.08 ; Chl(b) 4.523 ± 0.110 ; total chlorophyll 17.44 ± 0.13 mg/L ($N = 4$). The differences statistically significant were observed between the group with compost and extract: total chlorophyll $p = 0.0156$, Chl(a) $p = 0.0181$ and Chl(b) $p = 0.0489$.

This result indicates a positive effect of compost with algae on the quality of the crop. Among the nutrients that increase the content of chlorophyll in crops are mostly nitrogen and magnesium. The highest content of magnesium was found in samples of plants grown on medium supplemented with the compost

Table 5. Elemental composition of the cultivated *Lepidium sativum*

Element	Wavelength nm	Control "0"					Compost "C"					Extract "E"											
		mg/kg d.m.										mg/L											
		"0" 1	±SD	"0" 2	±SD	"0" 3	±SD	Mean	K 1	±SD	K 2	±SD	K 3	±SD	Mean	E 1	±SD	E 2	±SD	E 3	±SD	Mean	
Microelements	B	249.772	1.02	0.153	< LOD	–	< LOD	–	0.339	108	16.2	36.1	5.42	26	3.9	56.6	10.7	1.61	7.39	1.11	3.36	0.504	7.14
	Cu	267.716	10.7	1.61	10.3	1.55	11.9	1.79	11.0	9.6	1.44	12.8	1.92	9.26	1.39	10.6	7.98	1.20	8.89	1.33	8.4	1.26	8.42
	Fe	324.754	136	20.4	139	20.9	173	26.0	150	257	38.6	229	34.4	220	33	236	138	20.7	152	22.8	159	23.9	150
	Mn	257.61	37.2	5.58	38.7	5.81	38.5	5.78	38.1	51.5	7.73	51.6	7.74	48.2	7.23	50.4	47	7.05	48.3	7.25	49.7	7.46	48.3
	Mo	202.032	10.1	1.52	6.72	1.01	14.5	2.18	10.4	<LOD	–	14.2	2.13	13.9	2.09	9.35	11.8	1.77	8.6	1.29	7.06	1.06	9.15
Macroelements	Ni	231.604	< LOD	–	5.48	0.712	<LOD	–	1.83	<LOD	–	8.58	1.115	6.88	0.894	5.15	< LOD	–	< LOD	–	< LOD	–	< LOD
	Zn	213.857	142	21.3	171	25.7	184	27.6	166	258	38.7	232	34.8	254	38.1	248	252	37.8	361	54.2	370	55.5	327
	Ca	315.887	1444	289	1524	305	1593	319	1520	5742	1148	3413	683	3750	750	4302	2639	528	2604	521	2368	474	2537
	K	766.491	11642	2328	12244	2449	13880	2776	12588	38233	7647	35740	7148	37778	7556	37250	31775	6355	31964	6393	33139	6628	32293
	Mg	285.213	5694	1139	5976	1195	5955	1191	5875	8087	1617	7963	1593	8192	1638	8080	7354	1471	7570	1514	7834	1567	7586
Toxic elements	P	213.618	16346	3269	16380	3276	16294	3259	16340	18815	3763	18447	3689	18766	3753	18675	17212	3442	17096	3419	17711	3542	17340
	S	181.972	11317	2263	12441	2488	12881	2576	12213	15695	3139	16179	3236	16965	3393	16280	15349	3070	16618	3324	17288	3458	16418
	Cd	228.802	1.74	0.226	1.24	0.161	< LOD	–	0.994	3.44	0.447	1.32	0.172	1.02	0.133	1.93	1.92	0.250	1.32	0.172	1.33	0.173	1.52
	Cr	267.716	2.38	0.309	3.27	0.425	0.997	0.13	2.22	7.21	0.937	4.31	0.560	2.32	0.302	4.61	6.82	0.887	4.8	0.624	4.16	0.541	5.26
	Pb	220.353	< LOD	–	< LOD	–	< LOD	–	< LOD	< LOD	–	< LOD	–	< LOD	–	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Other elements	Al	308.215	31.3	4.70	30.4	4.56	53.5	8.03	38.4	975	146	212	31.8	106	15.9	431	29.6	4.44	37.3	5.595	18.9	2.84	28.6
	Co	228.615	< LOD	–	< LOD	–	< LOD	–	< LOD	0.578	0.087	< LOD	–	< LOD	–	0.1926	< LOD	–	< LOD	–	< LOD	–	< LOD
	Na	588.995	8642	1728	7530	1506	7087	1417	7753	9625	1925	8685	1737	10840	2168	9716	10506	2101	9210	1842	9500	1900	9739
	Si	251.611	91.4	13.7	95.6	14.3	134	20.1	107	280	42	196	29.4	260	39	245	74.1	11.1	207	31.1	81.1	12.2	121

* < LOD-below the limit of detection.

(approximately 8080 mg/kg d.m.) what was correlated with the content of chlorophyll. Magnesium is an essential component of chlorophyll, it intensifies the processes of photosynthesis acting in their key role because of the central place it occupies in a porphyrin system [54]. In addition, the compost on the algae basis can contain plant growth hormones responsible for stimulating of plant growth and increase the intensity of photosynthesis [43].

4 Concluding remarks

The study showed a significant positive impact of the compost derived from the Baltic algae on the growth of plants. Rich in micro- and macronutrients and low level of heavy metal content in compost and extract allow for the assumption that these products have a positive impact on plants crop. The height of the plants in the tests on the substrate with the addition of compost and the extract were significantly higher than the control sample. The highest yields (in terms of dry weight of the plant) were obtained from the sample containing the extract. The pH at 7, both the compost and the extract, allows for their agricultural use without the risk of soil acidification. Furthermore, the content of chlorophyll in plants grown on medium supplemented with the compost was significantly higher than the control sample. Moreover, the risk of odour nuisance of the used compost was excluded. The compost obtained from algae may be an alternative or addition to the range of preparations used in agriculture and valuable source of nutrients useful in crop production. The compost can be used as a substrate for the production of fertilizers or directly to fertilization.

Practical application

Nowadays, the drifting or thrown on the shore algal biomass is a problem, especially in the coastal areas. Non-removal of this biomass may result in its decomposition and emission of odours. Collected algae can be converted into valuable products for modern agriculture. Composting of algae for the natural fertilizers is the example of environmental biotechnology. Additionally, from the composted algae, liquid extract can be produced that can act as a biostimulant of plant growth. These processes are environmental friendly — they are not a nuisance due to the odour emissions. Both products have a positive effect on the plant growth, including height, weight, content of chlorophyll and micro- and macroelements. They can be recommended for the use in agricultural practices as a substitute or supplementation of the mineral fertilizers/chemical biostimulants, for example in horticulture.

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