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Evaluation of the Effect of Biostimulation on the Yielding of Golden Delicious Apple Trees

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Abstract: The aim of the study was to assess the impact of N Pro and Seactiv Complex technologies based on sea algae extracts on the yield and quality of Golden Delicious apple trees compared to the standard fertilization program. Research conducted in the years 2008–2017 showed that the tree fertilization technology and the year of research had a significant impact on the quality and yield parameters. The abundance of seaweed extracts had a positive effect on the greater number of fruits per tree (pcs.), their weight ($t \times ha^{-1}$; kg $tree^{-1}$), the percentage of fruits exceeding 7.5 cm in size (%) and the average weight of fruits (g) compared to the control combination. In most of the analyzed study years, total yield exceeded the 90 t × threshold regardless of the fertilization program. The use of technology based on sea algae extracts during 10 years of research had a positive effect on the quality and weight compared to the standard fertilization technology commonly used in cultivation.

Keywords: seaweed extracts; fertilization; fruit quality; fruit firmness; long-term research

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1. Introduction

Despite the rapid growth in crop production over the past few decades, food is still not sufficiently available for everyone, and we are still far from the UN's goal of zero hunger by 2030. It should be emphasized that fruit production is important not only for satisfying hunger but also for the intake of the dose of berries and fruits recommended by the WHO in the human diet. [1].

Today, apple trees are grown all over the world, and their fruits are highly valued by consumers [2]. Poland is one of the leaders in apple production in the world, and in Europe, it is the largest producer of apples. In order to meet current requirements, optimization of production technology is key [3]. Despite the fact that the cultivation of apple trees and the production of apples in temperate climate does not cause major problems, it is largely dictated by weather conditions during the growing season. In this climate, despite the optimization of cultivation, there are weather conditions that significantly reduce the yield and have negative impacts on quality. Therefore, it is very important for horticultural practice to optimize cultivation technology in order to minimize the adverse impact of weather conditions on production [4].

Mineral fertilizers, which contain essential nutrients for proper plant development and soil fertility, are used to replenish nutrient deficiencies, allowing for high yields [5]. Mineral fertilization largely contributes to the rapid growth of yields and is the basic agrotechnical treatment in horticultural production [6]. In order to increase the effectiveness of this treatment, biostimulants are increasingly used [7–9]. Biostimulants are currently viewed primarily as an additive to mineral fertilizers to promote uptake, increase resistance to abiotic stresses, and influence plant growth [10]. It has been proven that biostimulants can increase nutrient uptake efficiency by regulating the expression of transcription factors and genes [11]. The use of biostimulants is considered a good practice to reduce fertilizers and other chemicals, resulting in less environmental damage and is part of sustainable agricultural development [9]. Biostimulants manufactured from raw materials of natural origin, which are based on, among other things, seaweed extracts, micro-organisms, humic acids and protein hydrolysates [12,13], are considered to be environmentally friendly, which is particularly important in sustainable plant cultivation [14].

The popularity of seaweed-based preparations continues to grow rapidly, mainly due to their phytostimulant properties, phytoelicitor activity, initiation of phytohormal reactions, and positive effects on changes in soil and plant microbiome components [15]. It is believed that the maximum potential for the use of seaweed, which is considered a biological resource, has still not been reached. This also applies to biostimulants based on these raw materials, which, due to the lack of sufficient scientific knowledge about them, are still not fully optimally utilized in crop production [16].

Biostimulants based on seaweed extracts are a complex matrix of biologically active compounds [7] that contain large amounts of mostly organic substances, but small amounts of inorganic nutrients. Their composition includes polyphenolic compounds, minerals, polysaccharides, amino acids, phlorotannins, lipids, proteins, oxylipins, plant growth hormones, sterols, fatty acids and carotenoids [16,17]. Seaweeds from three clusters: *Phaeophyceae*, *Rhodophytai*, and *Chlorophyta* [14], are used for commercial agricultural purposes. Among brown seaweeds used for biostimulants, *Ascophyllum nodosum* (L.) is the best-studied species [18].

In order to improve plant production, biostimulation is used, and it is crucial to know the chemical composition of the available products in the market to apply them in appropriate doses and at developmental stages. It should also be noted that each plant species may react differently to a given biostimulant. To gain a basic understanding of how biostimulants work, extensive research is needed, which requires the cooperation of scientists from different fields as well as farmers themselves [8,19–23]. To date, there are a number of publications describing the impact of biostimulation on the production of fruit species; however, a detailed plan for using this technology throughout the entire growth period of plants has not been developed.

The aim of the research was to assess the impact of N Pro technology (specific N PRO complex—affects faster uptake and better conversion of nitrogen into protein) and Seactiv Complex, which is based on sea algae extracts, on the quality and yield of Golden Delicious apples.

The ten-year research aimed for a thorough assessment of innovative cultivation technologies and the confirmation of the validity of using biostimulating preparations in unstable climatic conditions.

2. Materials and Methods

The study was carried out from 2008 to 2017 in south-eastern Poland in the Sandomierz Upland (50°39′ N; 21°34′ E). The experimental material consisted of trees of the cultivar Golden Delicious germinated on the rootstock M.9. The trees were planted in the spring of 2003 at a spacing of 3.0 × 1.0 m on loess soil as one-year germinants. The crowns of the trees were guided in an axial form, and metal poles with wires and wooden stakes were used as supports in the rows. Within each combination, randomly analyzed characteristics from 100 vines were tested.

The experiment evaluated the yield and quality of apple trees of the Golden Delicious variety fertilized with two programs:

1st Control (standard fertilization program used on a daily basis in practice, based on macro and microelements):

- Yara Mila Complex (Hydrocomplex) 12-11-18–300 kg $\times$ ha^{-1} in sprinkled form at the green bud stage;
- Tropicote saltpeter–200 kg $\times$ ha^{-1} in sprinkled form after flowering;
- Agroleaf 52% P–5 kg $\times$ ha^{-1} in the form of a spray in the green bud phase;
- Agroleaf 52% P–5 kg $\times$ ha^{-1} in the form of a spray in the green bud phase;
- Calcinit–calcium nitrate–5 kg $\times$ ha^{-1} in the form of a spray in the green bud phase–7–10 days later–4 treatments at 7–10 day intervals;
- Calcium chloride–6 kg $\times$ ha^{-1} in the form of a spray in the green bud phase–6 treatments at 7–10 day intervals.

2nd Biostimulation (fertilization program based on macro and microelements and enriched with N Pro technology and Seactiv Complex, which is based on sea algae extracts and shows a biostimulating effect):

- Eurofertil 34 N Pro 8-8-17–300 kg in sprinkled form at the green bud stage;
- Sulfammo 30 N Pro–100 kg/ha in sprinkled form after flowering;
- Fertileader Leos–5 l $\times$ ha^{-1} in the form of sprays at the green bud stage;
- Fertileader Gold–3 l $\times$ ha^{-1} in the form of sprays at the pink bud stage;
- Fertileader Axis–3 l $\times$ ha^{-1} in the form of sprays after flowering;
- Fertileader Vital–3 l $\times$ ha^{-1} in the form of sprays-2 treatments at 10–14 day intervals;
- Fertileader Elite–3 l $\times$ ha^{-1} in the form of sprays-3 treatments from the walnut stage at 14-day intervals.

The combinations were trees fertilized with two technologies: standard (1) and enriched with N Pro technology and Seactiv Complex (2). The tested trees were fertilized every year throughout the test cycle in accordance with the above-mentioned recommendations developed throughout the experience. In both combinations, the value of macro and micronutrients was at a similar level.

The experiment was set up in a random block design consisting of 2 combinations in 5 repetitions. Replications were plots with 10 apple trees.

During the experiment, chemical thinning after flowering and manual correction after the fall of apple buds in June were performed every year, leaving a similar number of fruits on the tree. Measurements and observations carried out between 2008 and 2017 concerned fruit yield and quality. Fruit harvesting was carried out on 20–30 September, separately from each tree within each combination, by determining the number of fruits on the tree (pcs.). The date of harvest maturity was determined using starch samples and organoleptic evaluation. Fruit harvested separately from each tree was used to determine the yield (kg$\cdot$tree^{-1}; kg$\cdot$ha^{-1}). The commercial yield was determined on the basis of the percentage share of apples, >7.5 cm in diameter. The average weight of one apple (g) was determined. Fruit sizing was carried out on a randomly selected batch of 100 apples from each repetition. The firmness of the flesh in the fruit was determined using a firmness meter one day after harvesting on the basis of 10 apples from each repetition. The sugar extract content in the fruit was measured with an Abbe refractometer, determining the percentage of extract in the juice squeezed from 10 representative fruits from each repetition.

The results of the experiment were statistically analyzed via analysis of variance (ANOVA) at a significance level of 5% and using Tukey's test.

3. Results and Discussion

The average air temperature during the growing season in successive years of the study was higher than the multi-year average for 1988–2008. It was observed that only in April of 2015 was the average air temperature lower than the multi-year average, while in May, similar relationships were shown in 2008–2010 and 2015, June in 2009, July in

2008, 2011 and 2017, August in 2014, September in 2008, 2010, 2013 and 2017, while in October, in 2009–2010 and 2015–2016. The warmest year of the study was 2012, when the average air temperature in all months of the growing season was higher than the multi-year average, while the coolest year was 2010, whose average temperature from April to October was 14.3 °C, 0.1 °C higher than the multi-year average. The lowest average monthly air temperature was recorded in October 2010 (5.6 °C), while the highest was in August 2014 (22.5 °C) (Table 1).

Table 1. Average monthly air temperatures and total precipitation according to the Agrometeorological Station in Pęchów during the months of April to October in 2008–2017 (HortiProCam).

Air Temperature, °C								
	IV	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Average from April to October, °C**
2008	9.4	13.5	18.2	18.8	18.9	12.7	9.8	14.5
2009	11.1	13.7	16.6	20.2	18.5	15.1	7.2	14.6
2010	9.4	14.0	17.8	21.2	19.5	12.3	5.6	14.3
2011	10.8	14.3	18.5	18.1	19.0	15.5	8.0	14.9
2012	9.9	15.2	17.9	21.2	19.1	14.9	8.2	15.2
2013	9.0	15.1	18.3	19.5	19.5	12.2	10.3	14.8
2014	10.8	14.5	17.2	20.9	18.3	14.8	9.2	15.1
2015	8.5	13.2	17.3	20.1	22.5	15.4	7.3	14.9
2016	9.5	14.7	19.1	19.4	17.8	15.6	7.3	14.8
2017	7.6	14.1	18.7	18.7	19.6	13.3	9.0	14.4
Average temperature of the month, °C	10.0	14.4	18.7	19.7	19.7	14.7	8.9	14.7
Mean (1988–2008)	8.8	14.2	16.9	19.1	18.4	13.4	8.6	14.2
Total precipitation, mm								
	IV	V	VI	VII	VIII	IX	X	∑ precipitation, mm
2008	59.0	74.3	29.4	99.4	31.0	83.3	36.8	413.2
2009	7.6	72.6	89.2	71.7	57.8	44.7	101.2	444.8
2010	34.1	168.4	44.8	125.7	106.1	88.9	9.2	577.2
2011	49.9	30.7	55.5	382.9	17.8	5.9	23.8	566.5
2012	29.2	41.2	76.5	53.6	38.8	39.6	124.0	402.9
2013	31.8	88.6	111.2	33.4	14.9	73.6	5.4	358.9
2014	42.6	112.2	54.2	97.0	96.8	32.4	36.6	471.8
2015	20.2	75.0	34.0	84.0	5.0	90.2	34.0	342.4
2016	22.4	38.0	21.0	55.2	47.4	17.2	36.6	237.8
2017	80.6	49.6	31.4	26.6	44.2	77.0	72.4	381.8
Mean precipitation, mm	34.5	59.5	50.3	90.0	42.6	47.8	47.9	419.7
Mean (1988–2008)	45.7	57.0	68.7	82.4	58.7	57.0	37.9	361.7

The sum of precipitation analyzed for the period of April to October between 2008 and 2017 was higher (419.7 mm) than the multi-year average (361.7 mm). The driest years in the analyzed period were 2013 (358.9 mm), 2015 (342.4 mm) and 2016 (237.8 mm), whose precipitation totals were less than the multi-year average. The highest total rainfall was recorded in 2010 (577.2 mm). On average, from 2008 to 2017, the driest month was April, while the wettest month was July. The lowest precipitation was recorded in April 2009 (7.6 mm), while the highest was in May 2010 (168.4 mm) (Table 1).

Based on the obtained results, it was shown that the application of technology based on seaweed extracts had a significant effect on the yield and quality of Golden Delicious apple trees. Table 2 presents the differences between the applied fertilization technologies, regardless of the year of research (A), and in the next part, in particular years of research, regardless of the applied fertilization technology (B), and presents the integration of the factor of the year of research and fertilization technology (A × B). Statistical analysis showed that trees treated with seaweed extracts had higher number of apples per tree, percentage of fruit with a diameter of more than 7.5 cm and average fruit weight compared to the control.

Table 2. The effect of technology based on sea algae extracts on the size and quality of Golden Delicious apple trees yield.

		Number of Apples on the Tree	Yield	Yield	Marketable Yield	Fruit with Diameter >7.5 cm	Fruit Weight
		pcs.	kg·tree^{-1}	t·ha^{-1}		%	g
Variety (A)	Control	143.84 ± 13.69 b	25.53 ± 3.90 b	85.00 ± 12.97 b	70.99 ± 26.38 b	61.92 ± 25.82 b	183.90 ± 15.99 b
	Biostimu-lation	146.99 ± 19.75 a	27.69 ± 3.78 a	92.19 ± 12.58 a	83.10 ± 17.97 a	77.28 ± 21.18 a	193.90 ± 15.31 a
	p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year (B)	2008	159.8 ± 14.9 ab	28.2 ± 1.1 abc	94.1 ± 3.8 abc	70.5 ± 1.7 c	66.3 ± 1.1 c	177.5 ± 9.3 d
	2009	155.0 ± 1.9 bc	27.1 ± 6.5 bcd	90.4 ± 21.70 bcd	91.4 ± 3.9 a	83.4 ± 23.4 ab	207.5 ± 9.3 ab
	2010	114.8 ± 9.7 f	20.1 ± 0.8 ef	67.1 ± 2.7 ef	63.0 ± 27.3 d	41.6 ± 16.6 d	176.0 ± 7.7 d
	2011	160.7 ± 1.5 ab	28.9 ± 1.6 abc	96.4 ± 5.3 abc	80.5 ± 1.6 b	77.7 ± 5.8 b	180.5 ± 8.2 cd
	2012	146.4 ± 1.8 cd	27.8 ± 1.4 abc	92.6 ± 4.7 abc	86.5 ± 3.8 a	80.2 ± 7.6 b	190.0 ± 12.0 c
	2013	133.5 ± 1.6 e	24.2 ± 1.8 de	80.7 ± 6.1 de	89.5 ± 2.7 a	72.4 ± 7.7 b	181.5 ± 11.5 cd
	2014	144.0 ± 3.3 cd	26.0 ± 0.7 cde	86.7 ± 2.2 cde	89.5 ± 3.8 a	77.7 ± 5.3 b	181.0 ± 8.8 cd
	2015	169.5 ± 5.2 a	30.9 ± 2.8 a	102.9 ± 9.5 a	88.5 ± 4.9 a	90.7 ± 3.3 a	202.0 ± 1.1 b
	2016	140.5 ± 7.5 de	29.8 ± 1.03 a	99.2 ± 3.4 ab	90.5 ± 3.8 a	89.9 ± 6.9 a	218.0 ± 2.2 a
	2017	129.9 ± 3.2 e	22.8 ± 1.3 e	75.8 ± 4.3 e	20.4 ± 15.9 e	16.1 ± 12.7 e	175.0 ± 5.5 d
	p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
A × B	*p*-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

a, b,. . ., f—means that the different letters in the column show significant differences at α = 0.05.

The number of apples per tree ranged from 114.8 to 169.5 and differed significantly between the evaluated study years. It was shown that in 2015 the trees of the Golden Delicious variety had significantly the most apples throughout the study cycle, not depending on the fertilization combination used. Significantly the trees had the least fruit in 2010. The year 2010 was the coldest and wettest in the entire research cycle which had a direct impact on fruiting. In 2008, 2019, 2011 and 2015, the trees of the studied apple variety had more than 150 apples per tree while in 2010 and 2017 they had less than 130. Arthur et al. (2003) report that applications of preparations based on seaweed extracts contribute to earlier flowering, better fruit set and fruit emergence of many crops [24]. Biostimulant formulations based on seaweed extracts enhance plant growth [25–29], and have positive effects on flowering parameters [30–33].

Apple trees of the Golden Delicious variety had very good yields throughout the study cycle which were at a minimum level of 67.0 t × ha^{-1}. The fruit yield of the studied variety ranged from 20.1 to 30.9 kg × tree^{-1} tj. from 67.1 to 102. 9 t × ha^{-1}. Significantly the highest yield was obtained in 2015 and significantly the lowest in 2010. In 2008, 2009, 2011, 2012, 2015 and 2016 the total yield exceeded the threshold of 90 t × ha^{-1}, regardless of the fertilization program which accounts for 60% of the entire research cycle. The percentage of fruits with a diameter of more than 7.5 cm ranged from 20.4 to 91.4% and differed significantly between the studied years. There were no significant differences in the percentage of large fruits with a diameter of more than 7.5 cm in the years 2009, 2012–2016. The values of this parameter in the mentioned years oscillated from 86.5 to 91.4%. In 2017 the share of large fruits in the total yield was at the level of 20.4%, regardless of the method of fertilization applied to Golden Delicious apple trees. In the study by Marjańska-Cichoń and Sapieha-Waszkiewicz [34], it was proven that apple trees of the Elise, Šampion and Novamac cultivars on which the Goëmar BM 86® biostimulant was applied, foliarly had a higher total yield and a higher average weight and diameter of a single apple. The positive effect of the technology with biostimulation based on seaweed extracts on the percentage number of large fruits, i.e., with a diameter of more than 7.5 cm and on the marketable yield in each year of the study was shown by Kapłan et al. [4] where apple trees of the 'Szampion' variety were evaluated.

The commercial yield ranged from 16.1 to 90.7 t $\times$ ha^{-1}. A large scatter in the evaluation of this parameter was shown between the years of study. In 70% of the study years, the marketable yield was above 70.0 t $\times$ ha^{-1} and was significantly higher than in other years. Such a trend was observed in 2009, 2011–2016. 2017 had significantly the lowest commercial yield which reached the lowest level during the study period. Fruit weight ranged from 175.0 to 218.0 g regardless of the fertilization technology used. Significantly the heaviest apples were obtained in 2009, 2015 and 2016, the weight of a single fruit was at least 200.0 g. Apples with weight above 170.0 g were obtained in 2008, 2010 and 2017. The year 2010 was the least favorable for horticultural production. [35] showed that pear trees treated with the biostimulant Göemar BM® yielded more abundantly with pears having a larger diameter and weight of a single fruit. An increase in the quality of grape berries in the study of [36] was obtained after the application of a mixture of seaweed extract together with lime and magnesium. A positive effect on the apple weight after the application of such biostimulants was also demonstrated by [37] while [38] showed no effect of Goëmar BM 86 formulation based on marine algae extract on the average weight of single fruit and total yield in apple crops.

The yield volume of apple trees of the Golden Delicious variety during the 10 years of the study varied regardless of the combination used, from 64.6 t $\times$ ha^{-1} (2010-Biostimulation) to 111.6 t $\times$ ha^{-1} (2015-Control). In 8 of the 10 years of the study, the total yield of trees treated with biostimulant technology was higher than that in the control. Regardless of the combination used, the total yield during the entire study cycle was more than 60 t $\times$ ha^{-1} (Figure 1). The beneficial effect of preparations based on seaweed extracts on the yield quantity and quality was demonstrated by [39–44]. The above-mentioned correlations were confirmed in the present study. During the research, a favorable effect of fertilization technology based on seaweed extracts on total yield was demonstrated compared to standard fertilization technology.

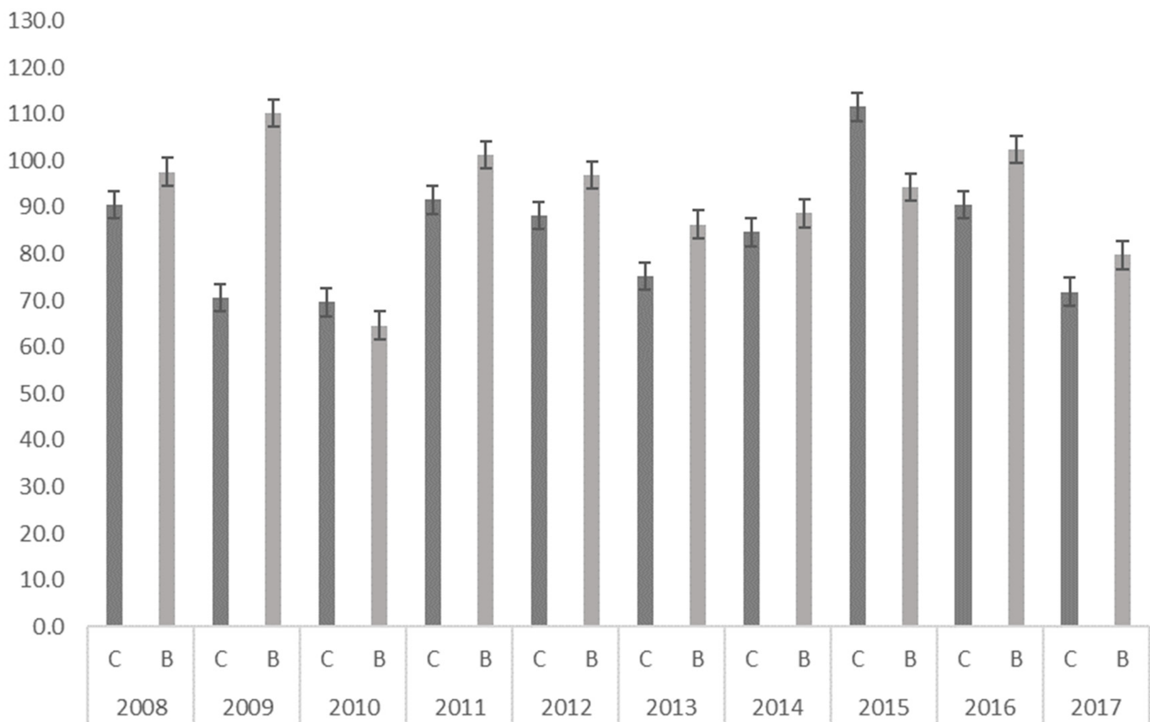

Figure 1. Yield (kg·ha^{-1}) evaluation of apple trees of Golden Delicious cultivar depending on fertilization technology (C—control; B—biostymulation).

The technology based on biostimulant preparations had a favorable effect on the size of the marketable yield throughout the study cycle, but a different relationship was shown only in 2015 (Figure 2). Commercial yield in Control ranged from 4.2 to 93.7 t $\times$ ha^{-1} while in trees treated with biostimulants from 27.9 to 104.7 t $\times$ ha^{-1}. The difference in commercial yield between the combinations used ranged from 2 to 42 tons. The largest yield diffeences were shown in 2009 (42.5 t); 2010 (30.4 t) and 2017 (23.7 t). It is worth noting that 2010 was the coldest and wettest year in the entire research cycle, similarly, in 2009, April recorded the lowest air temperatures of all the analyzed research years, while in 2017, the month of March was the coldest compared to the other research years, this had a direct impact on fruiting, It was shown that in 2009, 2010 and 2017, the biostimulant program, despite the inconvenient weather conditions, had a significantly favorable effect on the proportion of fruit above 7.5 cm and thus on the hand-lot yield. According to Ali et al. [45], 2020 plant-derived biostimulants improve target plant growth and yield due to the presence of various phytohormones and other secondary metabolites, vitamins, antioxidants and inorganic nutrients in the extract, which can directly affect plant growth and production by improving plant tolerance against abiotic stresses (Figure 2).

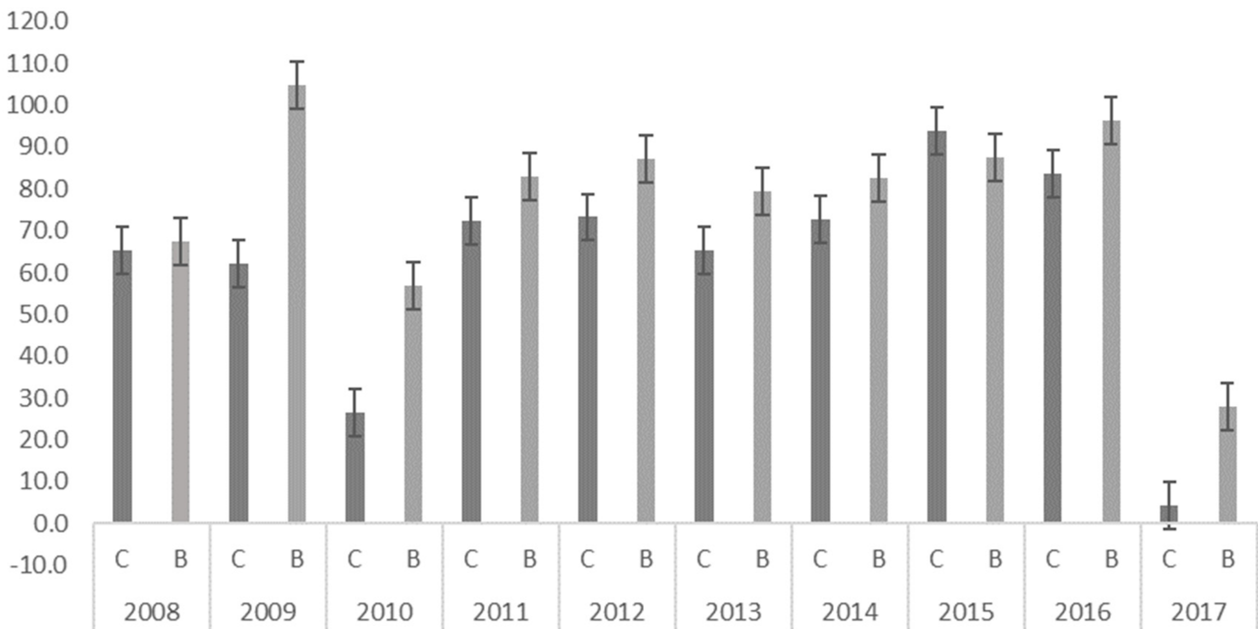

Figure 2. Influence of fertilization technology on the commercial yield (kg·ha^{-1}) of apple trees of the Golden Delicious variety (C—control; B—biostymulation).

Figure 3 shows a cluster analysis of the percentage of fruit >7.5 cm of Golden Delicious apple trees for the entire study cycle depending on the fertilization technology (Figure 3a for the control combination.; Figure 3b for the biostimulant technology). It was shown that in the case of the control, the years 2010 and 2017 strongly differed from the other clusters (study years), while in the case of the biostimulant technology, only 2017 differed from the other study years. It can be concluded that the application of seaweed-based preparations made it possible to achieve the percentage of large fruit in 2010 at the same level as in the rest of the study period and thus offset the impact of adverse weather conditions on the commercial yield. Similar observations were observed in 2017. According to Takuhara et al. [46], 2011, the CBF3 (C-repeat-binding factor) gene from the brown macroalgae species A. nodosum is activated in response to low temperatures and dehydration and is independent of ABA. Similarly, the COR15A gene regulates cold tolerance by stabilizing chloroplast membranes [47]. The above relationships and influences can be confirmed in the present field observations.

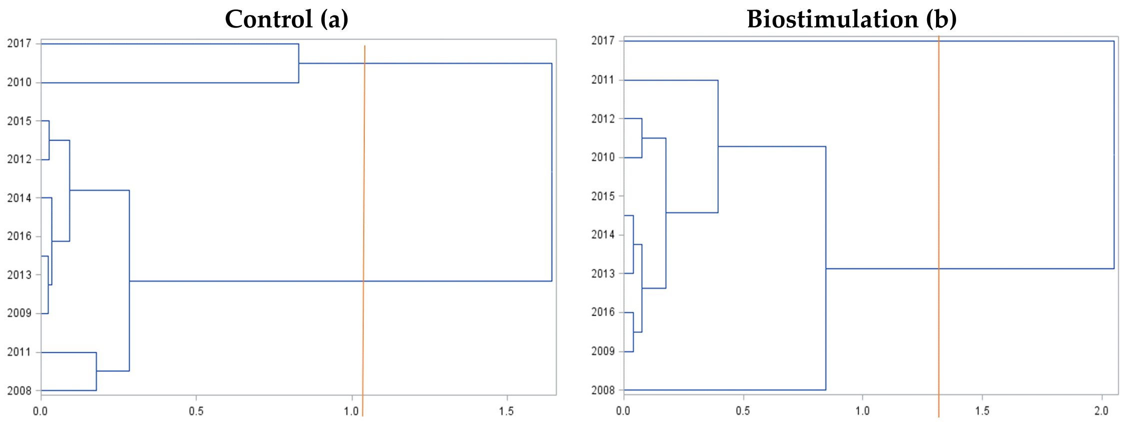

Figure 3. Cluster analysis for the parameter determining the percentage of fruit that is >7.5 cm in terms of Golden Delicious apple trees depending on fertilization technology.

The average weight of one fruit was more than 160.0 g (Figure 4). Biostimulant technology had a favorable effect on the evaluation of the studied parameter except in 2008 and 2015. The greatest differences in the weight of one fruit between the recorded combinations occurred in 2012 (22.0 g) and 2013 (21.0 g).

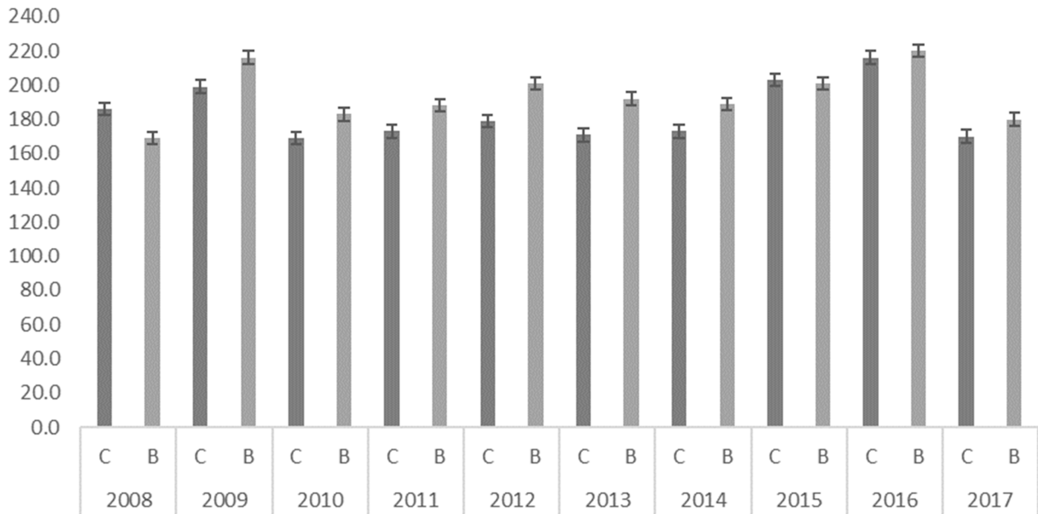

Figure 4. Effect of fertilization technology on fruit weight (g) of apple trees of Golden Delicious variety (C—control; B—biostymulation).

Correlation analysis showing relationships between weather conditions (monthly average air temperature and total precipitation), the year of the study and the parameters determining the quality and yield of Golden Delicious apple trees showed only significant negative relationships between total precipitation and yield (Table 3).

Table 3. Pearson's correlation coefficient for weather conditions, year of study and the parameters determining the quality and yield of Golden Delicious apple trees.

	Number of Apples on the Tree, pcs.	**Yield, kg·tree^{-1}**	**Yield, t·ha^{-1}**	**Marketable Yield, t·ha^{-1}**	**Fruit with Diameter >7.5 cm, %**	**Fruit Weight, g**
Temperature	0.0571	0.0236	0.0165	0.0238	0.0224	−0.0018
Precipitation	−0.2087	−0.2569	−0.2561 *	−0.1956	−0.1267	−0.2082
A year of research	−0.1665	0.0473	−0.0428	−0.1740	−0.2271	0.1872

* Significant difference at $\alpha = 0.05$.

Table 4 shows the correlation analysis carried out between yield quantity and quality parameters and the type of production technology, i.e., control (lower part of the table) and biostimulation (upper part of the table). It was shown that regardless of the method of fertilization, fruit weight did not correlate with the number of apples per tree. Similar correlations in the control were shown between the percentage number of fruits with a diameter >7.5 cm and total yield in apple trees of the Golden Delicious variety. Significantly positive correlations were shown between the other analyzed traits for yield size and quality regardless of the fertilization technology used.

Table 4. Pearson's correlation coefficient for parameters determining quality and yield of apple trees of the Golden Delicious variety.

	Number of Apples on the Tree, pcs.	Yield, kg·tree^{-1}	Yield, t·ha^{-1}	Fruit with Diameter >7.5 cm, %	Marketable Yield, t·ha^{-1}	Fruit Weight, g	
Number of apples on the tree, pcs.	1	0.6004 *	0.6004 *	0.6081 *	0.6851 *	0.3474	Biostimulation
Yield, kg·tree^{-1}	0.7663 *	1	0.9999 *	0.4765 *	0.7634 *	0.5548 *	
Yield, t·ha^{-1}	0.7663 *	0.9987*	1	0.4765 *	0.7634 *	0.5548 *	
Fruit with diameter > 7.5 cm, %	0.0758	0.3071	0.3071	1	0.9309 *	0.4660 *	
Marketable yield, t·ha^{-1}	0.4314 *	0.7388 *	0.7388 *	0.8655 *	1	0.5789 *	
Fruit weight, g	0.0946	0.5519 *	0.5519 *	0.5921 *	0.7460 *	1	
				Control			

* Significant difference at α = 0.05.

Fruit extract analyzed for the entire cycle, regardless of the year of study, did not differ significantly between the fertilization technologies. Apples treated with preparations based on seaweed extracts had a higher extract than controls (Figure 5). Similarly, a study by Lenart et al. 2022 [48] showed no significant effect of technology based on seaweed extracts on blueberry fruit extract. Similar relationships are discussed in Kapłan et al. [4] in the cultivation of apple trees of the 'Szampion' variety.

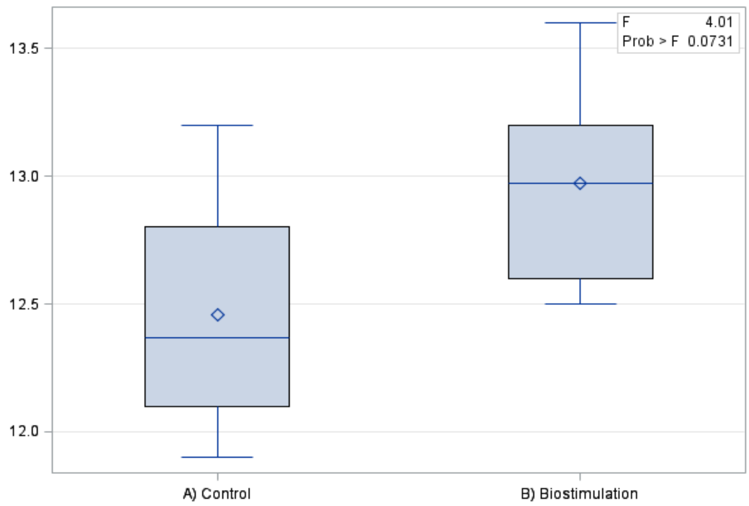

Figure 5. Golden Delicious apple fruit extract (Brix) depending on the technology used.

Regardless of the year of study, analyzed fruit firmness in the entire cycle did not differ significantly between the evaluated fertilization technologies. Apple trees fertilized with the standard program were less firm than those treated by the biostimulant technology. This confirms the study of [34] who showed that the application of a technology based on marine algae had a negligible effect on the firmness of fruit of apple cv. 'Champagne'. Fruit treated with the above technology had higher firmness than the control, but the differences were not significant. n an experiment conducted by [49], it was shown that the application of Seactiv technology in the form of a three-fold application of Fertileader Elite did not have a beneficial effect on the firmness of apple fruit at the harvest yield of the Pink Lady® Cripps Pink Cov. cultivar compared to a three-fold application of calcium chloride. It was found that, the fruits treated with Fertileader Elite after three months of storage had less firmness loss than the control (Figure 6).

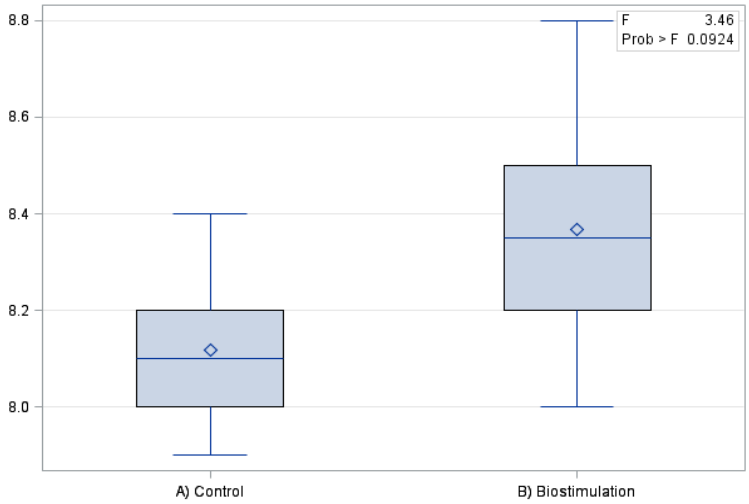

Figure 6. Fruit firmness (kg $\times$ cm^{-1}) of apple trees of the Golden Delicious variety depending on the technology used.

4. Summary

Research conducted in the years 2008–2017 showed that the fertilization technology of Golden Delicious apple trees and the year of research clearly influenced the weight and quality of the crop. Plants treated with sea algae extracts had a significantly higher number of apples per tree, yield, percentage of fruit with a diameter above 7.5 cm and average weight of apples in relation to the control combination. In most of the analyzed years of research, total yields exceeded the threshold of 90 t $\times$ ha, regardless of the fertilization program. In 8 out of the 10 years of research, the total yield of trees treated with biostimulation technology was higher than in the control. In 7 out of the 10 years of research, commercial yield exceeded 70 t $\times$ ha^{-1} and was significantly higher than in the remaining years. The technology based on biostimulating preparations had a positive effect on the commercial yield throughout the research cycle, and different relationships were demonstrated only in 2015. Fruit extract and fruit firmness for the entire cycle did not differ significantly between the evaluated fertilization technologies, regardless of the year of study. It was shown that the biostimulation program in the years with unfavorable weather conditions (2009, 2010 and 2017) significantly affected the percentage of fruit above 7.5 cm, and thus the marketable yield. Biostimulating preparations based on brown macroalgae extracts of species *A. nodosum* improve the ability of plants to cope with adverse weather conditions during apple cultivation. The use of biostimulation technology is highly recommended for practitioners. The above studies show a significant increase in qualitative and quantitative parameters from apple cultivation.

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References

1. The State of Food Security and Nutrition in the World 2020: Transforming Food System for Affordable Healthy Diets. 2020. Available online: https://www.fao.org/documents/card/en/c/ca9692en (accessed on 2 April 2023).
2. Liang, X.; Zhang, R.; Gleason, M.L.; Sun, G. Sustainable Apple Disease Management in China: Challenges and Future Directions for a Transforming Industry. *Plant Dis.* **2022**, *106*, 786–799. [CrossRef] [PubMed]
3. Pakuła, K.; Kuziemska, B.; Pieniak-Lendzion, K.; Trębicka, J. Produkcja jabłek w Polsce–aspekty środowiskowe, ekonomiczne i logistyczne. *Zesz. Nauk. SGGW-Ekon. I Organ. Gospod. Żywnościowej* **2018**, *122*, 81–93. [CrossRef]
4. Kapłan, M.; Baryła, P.; Krawiec, M.; Kiczorowski, P. Effect of N Pro technology and seactiv complex on growth, yield quantity and quality of 'Szampion' apple trees. Acta Sci. *Pol. Hortorum Cultus.* **2013**, *12*, 45–56.
5. Bafoev, A.X.; Rajabboev, A.I.; Niyozov, S.A.; Bakhshilloev, N.K.; Mahmudov, R.A. Significance and Classification of Mineral Fertilizers. *Tex. J. Sci.* **2022**, *5*, 1–5. Available online: https://zienjournals.com/index.php/tjet/article/view/777 (accessed on 1 April 2023).
6. Robertson, G.P.; Vitousek, P.M. Nitrogen in Agriculture: Balancing the Cost of an Essential Resource. *Annu. Rev. Environ. Resour.* **2009**, *34*, 97–125. [CrossRef]
7. Stirk, W.A.; Rengasamy, K.R.R.; Kulkarni, M.G.; van Staden, J. Plant Biostimulants from Seaweed. In *The Chemical Biology of Plant Biostimulants*; Geelen, D., Xu, L., Eds.; Wiley-Blackwell: Hoboken, NJ, USA, 2020; Volume 2.
8. Hasanuzzaman, M.; Parvin, K.; Bardhan, K.; Nahar, K.; Anee, T.I.; Masud, A.A.C.; Fotopoulos, V. Biostimulants for the Regulation of Reactive Oxygen Species Metabolism in Plants under Abiotic Stress. *Cells* **2021**, *10*, 2537. [CrossRef]
9. Mannino, G.; Campobenedetto, C.; Vigliante, I.; Contartese, V.; Gentile, C.; Bertea, C.M. The Application of a Plant Biostimulant Based on Seaweed and Yeast Extract Improved Tomato Fruit Development and Quality. *Biomolecules* **2020**, *10*, 1662. [CrossRef]
10. EU. Regulation of the European Parliament and of the Council Laying Down Rules on the Making Available on the Market of EU Fertilising Products and Amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and Repealing Regulation (EC) No 2003/2003. 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2019:170:TOC (accessed on 1 April 2023).
11. Campobenedetto, C.; Mannino, G.; Beekwilder, J.; Contartese, V.; Karlova, R.; Bertea, C.M. The application of a biostimulant based on tannins affects root architecture and improves tolerance to salinity in tomato plants. *Sci. Rep.* **2021**, *11*, 354. [CrossRef]
12. Yakhin, O.I.; Lubyanov, A.A.; Yakhin, I.A.; Brown, P.H. Biostimulants in Plant Science: A Global Perspective. *Front. Plant Sci.* **2017**, *7*, 2049. [CrossRef]
13. Rouphael, Y.; Spíchal, L.; Panzarová, K.; Casa, R.; Colla, G. High-Throughput Plant Phenotyping for Developing Novel Biostimulants: From Lab to Field or From Field to Lab? *Front Plant Sci.* **2018**, *9*, 1197. [CrossRef]
14. Admane, N.; Cavallo, G.; Hadjila, C.; Cavalluzzi, M.M.; Rotondo, N.P.; Salerno, A.; Cannillo, J.; Difonzo, G.; Caponio, F.; Ippolito, A.; et al. Biostimulant Formulations and *Moringa oleifera* Extracts to Improve Yield, Quality, and Storability of Hydroponic Lettuce. *Molecules* **2023**, *28*, 373. [CrossRef] [PubMed]
15. Ali, O.; Ramsubhag, A.; Jayaraman, J. Biostimulant Properties of Seaweed Extracts in Plants: Implications towards Sustainable Crop Production. *Plants* **2021**, *10*, 531. [CrossRef] [PubMed]
16. Khan, W.; Rayirath, U.P.; Subramanian, S.; Jithesh, M.N.; Rayorath, P.; Hodges, D.M.; Critchley, A.T.; Craigie, J.S.; Norrie, J.; Prithiviraj, B. Seaweed Extracts as Biostimulants of Plant Growth and Development. *J. Plant Growth Regul.* **2009**, *28*, 386–399. [CrossRef]
17. Craigie, J.S. Seaweed extract stimuli in plant science and agriculture. *J. Appl. Phycol.* **2011**, *23*, 371–393. [CrossRef]
18. Ugarte, R.A.; Sharp, G.; Moore, B. Changes in the Brown Seaweed *Ascophyllum Nodosum* (L.) Le Jol. Plant Morphology and Biomass Produced by Cutter Rake Harvests in Southern New Brunswick, Canada. *J. Appl. Phycol.* **2006**, *18*, 351–359. [CrossRef]
19. Lee, S.; Yoon, J.Y.; Jung, H.I.; Lee, D.J.; Shin, D.Y.; Hyun, K.H.; Kuk, Y.I. Ameliorative effects of squash (*Cucurbita moschata* Duchesne ex Poiret) leaf extracts on oxidative stress. *Plant Growth Regul.* **2012**, *67*, 9–17. [CrossRef]
20. Jannin, L.; Arkoun, M.; Ourry, A.; Laîné, P.; Goux, D.; Garnica, M.; Fuentes, M.; san Francisco, S.; Baigorri, R.; Cruz, F.; et al. Microarray analysis of humic acid effects on *Brassica napus* growth: Involvement of N, C and S metabolisms. *Plant Soil* **2012**, *359*, 297–319. [CrossRef]
21. Shekhar, S.H.S.G.; Lyons, C.; McRoberts, D.; McCall, E.; Carmichael, F.; Andrews, F.; McCormack, R. Brown seaweed species from Strangford Lough: Compositional analyses of seaweed species and biostimulant formulations by rapid instrumental methods. *J. Appl. Phycol.* **2012**, *24*, 1141–1157. [CrossRef]
22. Parađiković, N.; Teklić, T.; Zeljković, S.; Lisjak, M.; Špoljarević, M. Biostimulants research in some horticultural plant species—A review. *Food Energy Secur.* **2018**, *8*, e00162. [CrossRef]

23. Ma, Y.; Freitas, H.; Dias, M.C. Strategies and prospects for biostimulants to alleviate abiotic stress in plants. *Front. Plant Sci.* **2022**, *13*, 1024243. [CrossRef]
24. Arthur, G.D.; Stirk, W.A.; Van Staden, J. Efect of a seaweed concentrate on the growth and yield of three varieties of Capsicum annuum. *S. Afr. J. Bot.* **2003**, *69*, 207–211. [CrossRef]
25. El-Miniawy, S.M.; Ragab, M.E.; Youssef, S.; Metwally, A. Influence of Foliar Spraying of Seaweed Extract on Growth, Yield and Quality of Strawberry Plants. *Res. J. Appl. Sci.* **2014**, *10*, 88–94. Available online: https://www.researchgate.net/publication/263336797_Influence_of_Foliar_Spraying_of_Seaweed_Extract_on_Growth_Yield_and_Quality_of_Strawberry_Plants (accessed on 2 April 2023).
26. Hernández-Herrera, R.M.; Santacruz-Ruvalcaba, F.; Ruiz-López, M.A.; Norrie, J.; Hernández-Carmona, G. Effect of liquid seaweed extracts on growth of tomato seedlings (*Solanum lycopersicum* L.). *J. Appl. Phycol.* **2014**, *26*, 619–628. [CrossRef]
27. Szczepanek, M.; Wszelaczyńska, E.; Poberezny, J.; Ochmian, I. Response of onion (*Allium cepa* L.) to the method of seaweed biostimulant application. *Acta Sci. Pol. Hortorum Cultus* **2017**, *16*, 113–122. Available online: https://czasopisma.up.lublin.pl/index.php/asphc/article/view/2301 (accessed on 3 April 2023).
28. Soppelsa, S.; Kelderer, M.; Casera, C.; Bassi, M.; Robatscher, P.; Andreotti, C. Use of Biostimulants for Organic Apple Production: Effects on Tree Growth, Yield, and Fruit Quality at Harvest and During Storage. *Front. Plant Sci.* **2018**, *9*, 1342. [CrossRef]
29. Hassan, S.M.; Ashour, M.; Sakai, N.; Zhang, L.; Hassanien, H.A.; Gaber, A.; Ammar, G. Impact of Seaweed Liquid Extract Biostimulant on Growth, Yield, and Chemical Composition of Cucumber (*Cucumis sativus*). *Agriculture* **2021**, *11*, 320. [CrossRef]
30. Shankaraswamy, J.; Neelavathi, R.; Chovatia, R. Effect of Growth Regulators and Seaweed Extract on Vegetative Phenology in Mango (*Mangifera indica*). *Curr. Hortic.* **2015**, *3*, 30–34. Available online: https://www.indianjournals.com/ijor.aspx?target=ijor:chr&volume=3&issue=1&article=005 (accessed on 1 April 2023).
31. Aliko, A.A.; Manga, A.; Haruna, H.; Abubakar, A.W. Effect of different concentrations of aqueous *Ascophyllum nodosum* extract on flowering and fruiting in some vegetables. *BAJOPAS* **2017**, *10*, 63. [CrossRef]
32. Al-Shatri, A.H.N.; Pakyürek, M.; Yaviç, A. Effect of Seaweed Application on the Vegetative Growth of Strawberry cv. Albion Grown under Iraq Ecological Conditions. 2019. Available online: https://aloki.hu/pdf/1801_12111225.pdf (accessed on 6 April 2023).
33. Hussain, H.I.; Kasinadhuni, N.; Arioli, T. The effect of seaweed extract on tomato plant growth, productivity and soil. *J. Appl. Phycol.* **2021**, *33*, 1305–1314. [CrossRef]
34. Marjańska-Cichoń, B.; Sapieha-Waszkiewicz, A. The effect of Goëmar BM 86 on the yield of three apple varieties, and selected qualitative characteristics of Apple. *J. Plant Prot. Res.* **2012**, *52*, 1193–1199. [CrossRef]
35. Colavita, G.; Spera, N.; Blackhall, V.; Sepulveda, G. Effect of seaweed extract on pear fruit quality and yield. *Acta Hortic.* **2011**, *909*, 601–607. [CrossRef]
36. Calzarano, F.; Di Marco, S. Further evidence that calcium, magnesium and seaweed mixtures reduce grapevine leaf stripe symptoms and increase grape yields. *Phytopathol. Mediterr.* **2018**, *57*, 459–471. [CrossRef]
37. Ayub, R.; Sousa, A.; Viencz, T.; Botelho, R. Fruit set and yield of apple trees cv. Gala treated with seaweed extract of Ascophyllum nodosum and thidiazuron. *Rev. Bras. Frutic.* **2019**, *41*, e-072. [CrossRef]
38. Basak, A. The effect of seaweed product goëmar BM 86 and pollinus, on the performance of chemical thinning using NAA and BA. *Acta Hortic.* **2012**, *932*, 109–115. [CrossRef]
39. Roshdy, K.A. Effect of spraying silicon and seaweed extract on growth and fruiting of grandnaine banana. *Egypt. J. Agric. Res.* **2014**, *92*, 979–991. [CrossRef]
40. Ravi, I.; Kamaraju, K.; Kumar, S.; Sri, S.; Nori, S. Foliar Application of Seaweed Bio Formulation Enhances Growth and Yield of Banana cv. Grand Naine (AAA). 2018. Available online: https://www.researchgate.net/publication/324719817_Foliar_Application_of_Seaweed_Bio_Formulation_Enhances_Growth_and_Yield_of_Banana_cv_Grand_Naine_AAA (accessed on 8 April 2023).
41. Weber, N.; Schmitzer, V.; Jakopic, J.; Stampar, F. First fruit in season: Seaweed extract and silicon advance organic strawberry (*Fragaria* × *ananassa* Duch.) fruit formation and field. *Sci. Hortic.* **2018**, *242*, 103–109. [CrossRef]
42. Ghafouri, M.; Razavi, F.; Arghavani, M.; Gheslaghi, A.E. Improvement of Postharvest Traits of Kiwi Fruit (*Actinidia deliciosa* L. cv. Hayward) by Seaweed (*Ascophyllum nodosum*) Application. *J. Hortic. Sci.* **2023**, *36*, 885–901. [CrossRef]
43. Khan, A.S.; Munir, M.; Shaheen, T.; Tassawar, T.; Rafiq, M.A.; Ali, S.; Anwar, R.; Rehman, R.N.U.; Hasan, M.U.; Malik, A.U. Supplemental foliar applied mixture of amino acids and seaweed extract improved vegetative growth, yield and quality of citrus fruit. *Sci. Hortic.* **2022**, *296*, 110903. [CrossRef]
44. Rana, V.S.; Sharma, V.; Sharma, S.; Rana, N.; Kumar, V.; Sharma, U.; Almutairi, K.F.; Avila-Quezada, G.D.; Abd_Allah, E.F.; Gudeta, K. Seaweed Extract as a Biostimulant Agent to Enhance the Fruit Growth, Yield, and Quality of Kiwifruit. *Horticulturae* **2023**, *9*, 432. [CrossRef]
45. Ali, Q.; Shehzad, F.; Waseem, M.; Shahid, S.; Hussain, A.I.; Haider, M.Z.; Perveen, R. Plant-based biostimulants and plant stress responses. In *Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives*; Springer: Singapore, 2020; Volume 1, pp. 625–661. [CrossRef]
46. Takuhara, Y.; Kobayashi, M.; Suzuki, S. Low-temperature-induced transcription factors in grapevine enhance cold tolerance in transgenic Arabidopsis plants. *J. Plant Physiol.* **2011**, *168*, 967–975. [CrossRef]

47. Thalhammer, A.; Bryant, G.; Sulpice, R.; Hincha, D.K. Disordered cold regulated15 proteins protect chloroplast membranes during freezing through binding and folding, But do not stabilize chloroplast enzymes in vivo. *Plant Physiol.* **2014**, *166*, 190–201. [CrossRef] [PubMed]
48. Lenart, A.; Wrona, D.; Klimek, K.; Kapłan, M.; Krupa, T. Assessment of the impact of innovative fertilization methods compared to traditional fertilization in the cultivation of highbush blueberry. *PLoS ONE* **2022**, *17*, e0271383. [CrossRef] [PubMed]
49. Yvin, J.C.; Dufils, A. Incidences of Fertileader Elite® foliar spray applications on the improvementof Fruits quality and their conservation. Trials realized on Pink Lady® Cripps Pink Cov. *J. Hort. Forest. Biotech.* **2010**, *14*, 1–4.