BIO Web of Conferences **108**, 08006 (2024) https://doi.org/10.1051/bioconf/202410808006
IDSISA 2024

The effect of activated water on the photosynthetic processes of plants

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Abstract. The article is devoted to the research of the effect of nutrient solutions prepared on the basis of activated water: anolyte and catholyte on glucose synthesis during photosynthesis using the example of seedlings of vegetable crops: Japanese cabbage of the Mizuna variety, peas of the vegetable variety "Zima", cucumber of the variety "Vsyo putyom". The research was carried out to determine the mechanism of activated water influence on photosynthesis. As a result, the proposed working hypothesis on the effectiveness of the activated water influence on photosynthetic processes was confirmed. It has been shown that glucose synthesis is closely related to the reduction of absorbed CO_2 by $NADPH^+$ and ATP during photophosphorylation, and then their direct participation in this synthesis. It has been established that the increased concentration of hydrogen protons formed during the photolysis of activated water is the reason for the effectiveness of glucose synthesis, and, consequently, productivity. It has been shown that positively charged hydrogen ions H^+ involved in photophosphorylation, forming $NADPH^+$, which together with H^+ is involved in glucose synthesis, during photolysis of water during photosynthesis have a concentration of ions $3.13 \cdot 10^5$ times higher in anolyte ($534.67 \cdot 10^{-4}$ M/l) than in inactive water ($170.67 \cdot 10^{-9}$ M/l), which provides, in comparison with the control, an increase in glucose synthesis by 26.7% for Japanese cabbage of the Mizuna variety; by 39.7% for peas of the vegetable variety "Zima" and by 33.3% for cucumber of the variety "Vsyo Putyom". At the same time, for plants of vegetable peas "Zima", an increase in the intensity of growth in the anolyte was noted in comparison with the control by 12.5%.

1 Introduction

Activated water (AW) [1] is water containing an excessive amount of charged particles, electrons. The pH level of ordinary water is 7.0, activated alkaline (catholyte) 9, while the ORP (redox potential) in millivolts has negative values, and the water is enriched with molecular hydrogen and hydroxyl ions. It helps to accelerate metabolic processes in tissues, wound healing, and improve the general condition of the body.

In turn, activated acidic water (anolyte) exhibits bactericidal, astringent and coagulating properties. These two types of activated water are obtained in an electrolyzer having two electrodes: an anode with a positive potential and a cathode with a negative potential.

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Accordingly, an anolyte is formed in the anode region, and a cathode is a catholyte. The electrodes are separated by an ion permeable membrane that prevents the mixing of anolyte and catholyte. This set of randomly discovered properties of electrochemically activated water (ECHA water) gave rise to calling the catholyte “alive” and, accordingly, the anolyte “dead” water [2], having a low pH, that is, it has acidic properties and a weak antibacterial effect.

In a simplified form, the main processes occurring in the electrolyzer can be represented as follows [2]:

1) on anode: $2H_2O - 4e \rightarrow 4H^+ + O_2$;

2) on cathode: $2H_2O + 2e \rightarrow H_2 + 2OH^-$.

To understand the mechanism of activated water action on production processes in plants, let's consider the main production mechanism – photosynthesis, firstly, in terms of those of its functional components where water is involved and, secondly, those of its physico-chemical processes of interest to us related to its special properties, such as an increased concentration of protons hydrogen H^+, hydroxyl groups OH^-, oxygen O_2 and others [3].

The functional components include the process of carbohydrate or glucose synthesis, and one of the fundamental processes that directly affect glucose production – photolysis of water, decomposing water under the action of light into: $H_2O \rightarrow H^+ + OH^-$, and taking place in the light-dependent phase of photosynthesis [4].

Carbohydrates are an extensive class of organic compounds with a generalized formula (C_n, H_n, O_n), the formation of which is associated with the photosynthesis process. One type of carbohydrate is the polysaccharide cellulose. Cellulose is the main building material of plant tissues. It performs supporting functions in plants and gives them mechanical strength [5].

Glucose obtained as a result of photosynthesis is rich in energy, and is used by plants in the following main directions: part of glucose goes to build even more complex substances; for respiration, it decomposes to carbon dioxide and water; turns into a reserve organic substance starch, which can be used as an energy source in the absence of lighting. Glucose helps plants participate in the phenological phases of development [6]. Forming carbohydrates, glucose molecules, when combined with soil nitrates, form amino acids, which combine to synthesize proteins.

Photosynthesis is the conversion of light energy into energy of complex chemical bonds of organic substances with the participation of photosynthetic pigments, occurring in chloroplasts [7].

In the light-dependent phase, a photon of light, hitting the chlorophyll, excites it, electrons are released and accumulate on the outer membrane of the chloroplast. After the chlorophyll has lost all its electrons, the quantum of light continues to affect the water, causing H_2O photolysis: $H_2O \rightarrow H^+ + OH^-$.

Positively charged hydrogen protons accumulate on the inner membrane of the chloroplast. It turns out negatively charged electrons on the one hand, positively charged hydrogen protons on the other, and a membrane between them. Hydroxyl ions are used to produce oxygen and water: $4OH^- \rightarrow O_2 + 2H_2O$. When the number of hydrogen protons and electrons reaches a maximum, ATP synthase is triggered.

ATP synthase pushes hydrogen protons into the stroma, where they are picked up by a special carrier of hydrogen protons in carbohydrate reactions nicotine-amide-dinucleotide-phosphate (NADP). The passage of positive hydrogen ions (protons) through ATP synthase is accompanied by the synthesis of ATP molecules from ADP, the addition of one phosphate, called photophosphorylation, forming $NADPH^+$. At this point, the light phase of photosynthesis ends, and NADPH and ATP pass into the dark phase, where the CO_2 absorbed by the plant is restored in the chloroplast stroma with the help of NADPH and ATP, and its further participation in glucose synthesis takes place.

 https://doi.org/10.1051/bioconf/202410808006

To get one glucose molecule, as many as six reactions take place and six molecules of CO_2, eighteen molecules of ATP, twelve $NADPH^+$ and twenty-four protons of hydrogen H^+ are spent on its construction [4].

2 Materials and methods

To develop a methodology for experimental research, it is important to formulate a working hypothesis of the effectiveness of the activated water effect on photosynthetic processes. It follows from the above provisions that glucose synthesis is closely related to the reduction of absorbed CO_2 with the help of NADPH and ATP in the process of photophosphorylation, and then their direct participation in this synthesis. That is, it can be assumed that the increased concentration of hydrogen protons formed during the photolysis of activated water is the reason for the effectiveness of glucose synthesis, and, consequently, productivity. Hence, we conclude that research needs to be conducted in two directions:

(1) – confirmation of the increase in ion concentration during photolysis of activated water in its various states: activated (anolyte, catholyte) in comparison with non-activated;

(2) – confirmation of the growth of glucose synthesis when feeding plants with activated water.

Recall that activated water has two types: catholyte and anolyte. In this case, the catholyte is enriched with H_2 and ions of the hydroxyl group OH^-, and the anolyte with hydrogen protons H^+ and O_2. Since the photolysis process is the main direct supplier of H^+ for glucose synthesis, as well as indirect in the production of water and oxygen from hydroxyl groups of OH^-, the effectiveness of this process directly depends on the concentration of H^+ and OH^- ions, an increase in which occurs when water is activated.

Experiments in the first direction (1) were carried out according to the following method. Samples of activated and ordinary non–activated water were irradiated with ultraviolet (UV) light from a 350 W OUFK - 240 quartz lamp, placing the samples in three cuvettes.

The experiments were carried out by measuring the concentration three times for each of the samples and taking the average value of each of the three samples for final analysis, while pH, H_2 in ppm and ORP in mV were measured using a YY-400 water tester with calibration chemicals. Then the concentrations of C_{H+} and C_{OH-} were calculated - according to the pH readings for H^+ and pOH for OH^-. The calculation was performed using the following provisions.

The excess of H^+ ions determines the acidic properties of the solution, while the excess of OH^- ions determines the basic properties of the solution.

Since the ions are very small, and even in a small volume of water they contain a huge amount, the concentration of ions is usually expressed in moles per liter, where 1 mol is a "portion" equal in quantity to the Number of Avogadro = 6.02 * 1023 pieces.

For example, the concentration of hydrogen ions C_{H^+} = 0.01 mol per liter was determined from the expression pH = -log(0.01) = -(-2) = 2, taking the antilogarithm of the pH value.

There is a relationship pH + Rhone =14 between pH and pOH [8]. In addition to pH, the concentration of dissolved hydrogen H_2 was measured in ppm, ORP in mV.

In the second direction (2), research is devoted to the effect of nutrient solutions prepared on the basis of activated water – anolyte and catholyte, on glucose synthesis during photosynthesis, using the example of seedlings of vegetable crops: Japanese cabbage "Mizuna", vegetable peas "Zima" and cucumber "Vsyo putyom". To do this, three samples of each culture were planted for research in anolyte, catholyte and inactivated water. A total of nine samples.

Glucose concentration values were measured with three repetitions using a digital refractometer MA873 (Fig. 1). To do this, using a special press, one sample of the chloroplast stroma of each of the nine plants was isolated and placed in the measuring window of the

 https://doi.org/10.1051/bioconf/202410808006

refractometer. For subsequent analysis, the average value of the measured concentration was taken.

Fig. 1. Digital refractometer for the determination of glucose in plant objects.

3 Results and discussion

Confirmation of the increase in ion concentration during photolysis of activated water in its various states: activated (anolyte, catholyte) in comparison with non-activated, calculations were performed (Table 1), where the results of ion concentration measurements during photolysis of activated and non-activated water are given. The values of the concentrations of H^+ and OH^- ions are given here, the values of which characterize the physico-chemical processes associated with photosynthesis and affect glucose synthesis and significantly exceed the same indicators of inactivated water.

Table 1. Results of ion concentration measurements during photolysis of activated and non-activated water.

Activation phase	Parameters	Average values by exposure			Experiment averages
Activated catholyte	pH	8.70	8.80	8.90	8.80
	pOH	5.30	5.20	5.10	5.20
	C_{OH-}, M/l·10^{-6}	501.00	631.00	794.00	642.00
	H_2, ppm	0.22	0.53	0.31	0.35
	ORP, mV	-28.60	-250.33	-152.25	-143.73
Activated anolyte	pH	3.47	3.17	3.23	3.29
	C_{H+}, M/l·10^{-4}	339.00	676.00	589.00	534.67
	ORP, mV	530.00	503.33	541.67	525.00
Control sample (CS) Non-activated water	pH	8.74	8.73	8.84	8.77
	pOH	5.26	5.27	5.16	5.23
	C^{H+}, M/l·10^{-4}	182.00	186.00	144.00	170.67
	C_{OH-}, M/l·10^{-6}	550	537	692	593
	ORP, mV	69.80	46.00	77.25	64.35

 https://doi.org/10.1051/bioconf/202410808006

For clarity, we will construct a diagram, Figure 2, of the ion concentrations of activated – anolyte, catholyte and non-activated water. The concentrations of ions in water after photolysis are shown here in a visual form. The values of ion concentrations are expressed by column heights, which are significantly higher than their analogues for inactive water.

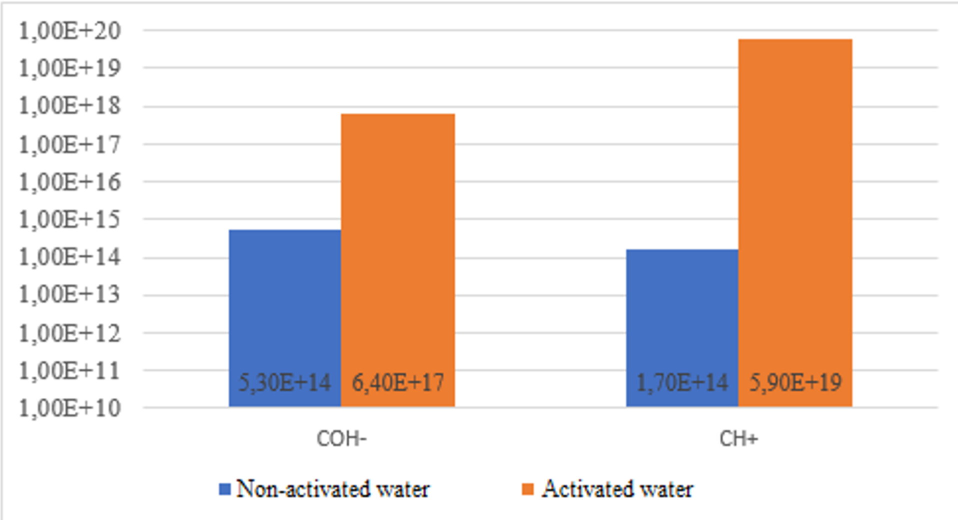

Fig. 2. Concentration of ions in water after photolysis. Samples No. 1 – comparison of control (non-activated water) with catholyte (activated water) by the number of ions of C_{OH-}; Samples No. 2 - comparison of control (non-activated water) with anolyte (activated water) by the number of ions of C_{H+}.

Confirmation of the growth of glucose synthesis when feeding plants with activated water, calculations were performed (Table 2), which provides the results of measurements of the concentration of glucose synthesis of vegetable crops when fed with different water options.

Table 2. The results of measurements of the concentration of glucose synthesis of vegetable crops when fed with different water options.

Culture	Non-activated water (CS) pH = 7.1 ORP = 165 mV	Anolyte pH = 3.6 ORP = 750 mV	Catholyte pH = 9.3 ORP = - 840 mV
	Average value of glucose concentration G, %		
Japanese cabbage "Mizuna"	2.2	3.0	2.9
Vegetable peas "Zima"	3.5	5.8	3.8
Cucumber "Vsyo putyom"	1.8	2.7	2.4
G growth of Japanese cabbage "Mizuna", %	-	26.7	24.1
G growth, peas vegetable "Zima", %	-	39.7	7.9
G growth of cucumber "Vsyo putyom", %	-	33.3	25.0

The concentrations of glucose synthesis of vegetable crops are shown below in a visual form when fed with various waters: No. 1 – Non-activated water (CS) pH = 7.1, ORP = 165 mV, No. 2 - Anolyte pH = 3.6; ORP = 165 mV, No. 3 – Catholyte pH = 9.3, ORP = - 840 mV.

 https://doi.org/10.1051/bioconf/202410808006

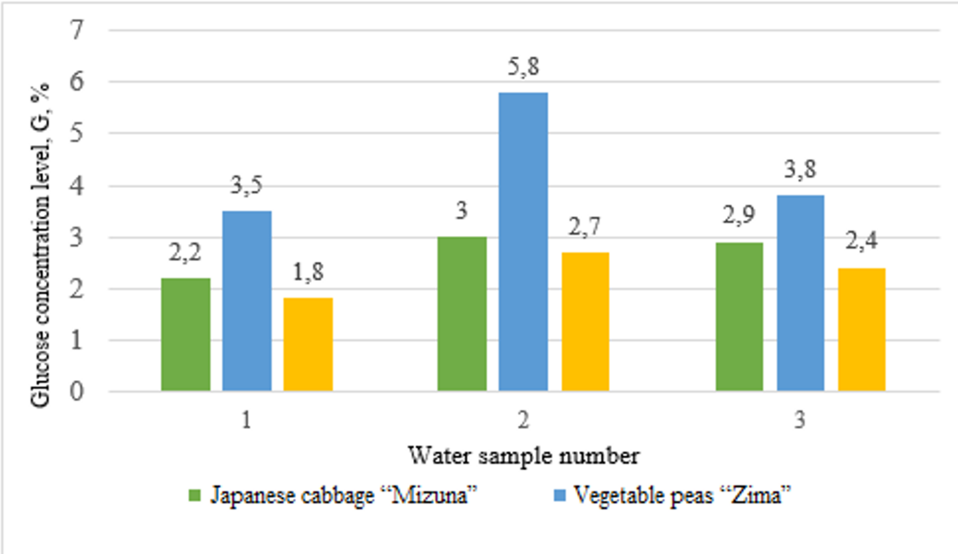

Fig. 3. The concentration of glucose synthesis of vegetable crops when fed with various waters: No. 1 – Non-activated water (CS) pH = 7.1, ORP = 165 mV, No. 2 - Anolyte pH = 3.6; ORP = 165 mV, No. 3 – Catholyte pH = 9.3, ORP = - 840 mV.

As a model object for the study of the influence of different variants of water used as a basis for plant nutrition, we selected the Zima pea crop for the analysis of growth processes in dynamics. The indicators were determined during two 6 and 8 day exposure periods (Fig. 4 and 5). Measurements showed an increase in the intensity of growth in the anolyte by 12.5% over two days compared with the control and other experiment options.

Fig. 4. Vegetable pea plants of the variety "Zima" on the 6th day of germination: samples 1, 2 in anolyte with mineral solution, samples 9, 10 in non-activated water with the same solution.

Fig. 5. Vegetable pea plants of the variety "Zima" on the 8th day of germination: samples 3, 4 in catholyte with mineral solution, samples 9, 10 in non-activated water with the same solution.

In the first direction (1). The experiment results confirmed the hypothesis put forward about the increase in ion concentration during photolysis of water in its various activated states: anolyte, catholyte in comparison with inactive. That is, an increase in the concentration of ions occurs when water is activated. Thus, the Сон- in the catholyte is increased on average by $3.76 \cdot 10^3$ times compared to the concentration of ions in inactive water, and the concentration in the anolyte, on average, with the same comparison, by $3.13 \cdot 10^5$ times.

In the second direction. The experiment results confirmed the hypothesis of an increase in glucose concentration. The increase in glucose synthesis when feeding plants with activated water for crops of Japanese cabbage of the Mizuna variety, vegetable peas of the variety "ZIma" and cucumber of the variety "Vsyo putyom" amounted to 26.7%, 39.7% and 33.3%, respectively, for anolyte and 24.1%, 7.9% and 25.0% for catholyte. At the same time, for plants of vegetable peas "Zima", an increase in the intensity of growth in the anolyte was noted by 12.5% in two days.

5 Conclusions

The proposed working hypotheses have been fully confirmed. Positively charged hydrogen ions H^+, involved in photophosphorylation, forming $NADPH^+$ and which is involved together with H^+ in glucose synthesis, have a $3.13 \cdot 10^5$ times higher concentration in anolyte than in inactive water during photolysis of water during photosynthesis. This ensures an increase in glucose synthesis by 26.7% for Japanese cabbage of the Mizuna variety, by 39.7% for vegetable peas "Zima" and 33.3% for cucumber "Vsyo putyom". At the same time, for plants of vegetable peas "Zima", an increase in the intensity of growth in the anolyte by 12.5% was noted for two days of germination.

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