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THE EFFECT OF NITROGEN FERTILIZATION ON NUTRIENT UPTAKE OF CUCUMBERS GROWN IN GROWING MEDIA WITH WOOD FIBER

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Greenhouse plants are usually grown in containers filled with growing media. Peat is the main component of the growing media used in greenhouses. However, peat substrate is made from peat from drained peatlands, which is a limited resource. Wood fiber can be an alternative to use as a growing media for controlled-climate crops. The chemical properties of the growing media interact and change continuously due to the small volume of the growing media, which is limited by the vegetative container. Therefore, this study aims to gain new knowledge on the impact of nutrient changes in the microbial degradation of carbon compounds in wood fiber and mixtures with peat substrate on the content and uptake of nutrients required by plants. Cucumbers (*Cucumis sativus* L.) were cultivated in growing media of peat substrate and wood fiber: 1) peat substrate (PS); 2) wood fiber (WF); 3) WF and PS 50/50 v/v; 4) WF and PS 25/75 v/v. The rates of fertilization were the following: 1) conventional fertilization; 2) N_{13}; 3) N_{23}; 4) N_{30}. Fertilization of cucumbers with different rates of nitrogen influenced the nutrient uptake. Plants grown in 50/50 and 25/75 growing media had the best Cu uptake when fertilized with N_{23}. When the plants grown in the wood fiber and in the 50/50 media were fertilized with N_{13}, $N_{23,}$ and N_{30}, the Mn content in the growing media at the end of the growing season was significantly lower than the Mn content in the media with conventional fertilization. Thus, nitrogen improved the uptake of Mn by plants grown not only in the wood fiber but also in combinations with peat substrate. Growing plants in wood fiber and fertilizing them with N_{23} can result in optimum uptake of micronutrients.

***Keywords**: substrate mixtures, growing media, nutrient uptake.*

INTRODUCTION

Decreasing arable land, increasing urbanization, water scarcity, and climate change are putting pressure on agricultural producers, while the world's rapidly growing population is creating a growing demand for healthy, fresh food (Gruda, 2019; FAO, 2018). As a solution, growing crops in greenhouses, and artificial and natural substrates will increasingly be the technology of choice (Gruda et al., 2019; Asaduzzaman et al., 2015; Raviv, 2013). Substrates made of peat and coconut fiber are commonly used for greenhouse vegetable production due to the good physical properties of these materials (Wallach, 2019). Research results have shown improved plant growth, development, and fruiting in upland peat and coir substrates compared to perlite in different substrate systems due to higher water retention, cation exchange capacity, and organic matter content (Böhme et al., 2005; Ayipio et al., 2021). Peat is the most widely used substrate due to its excellent chemical, biological, and physical properties (Savvas, Gruda, 2018; Kern, et al., 2017; Barrett et al., 2016). However, natural peat resources are often used for this solution, which are important as part of the ecosystem and have been formed over several thousand years. Growing concerns about the environmental impact of depleted peatlands have led to the use of industrial, domestic, and agricultural residues for greenhouse crop production (Barrett et al., 2016; Carlile et al., 2015). Wood-based substrates are more sustainable than peat, readily available, and cheaper than coconut fiber. Studies have shown that wood fiber substrate can be superior to mineral wool in terms of cucumber yield (Gajc-Wolska, 2008). To evaluate the organic matrix, the study assessed five organic substrates (Sphagnum peat, medium-quality pine bark, coarse pine bark, coconut fiber, and wood fiber) for cucumber cultivation in a greenhouse. The productivity and fruit quality of cucumbers grown in these substrates were better compared to the productivity of cucumbers grown in perlite. Preliminary studies have shown that better results are obtained when growing vegetables in a mixture of peat and pine bark. (Yang et al., 2022). Wood pulp is characterized by a low bulk density, high total porosity, and very high air content (Gruda and Schnitzler, 2004; Domeno et al., 2010), which results in a higher oxygen diffusion rate compared to peat (Clemmenson, 2004; Dorais et al., 2006). Microorganisms colonizing wood substrates extract carbon mainly from polysaccharide components and nitrogen fertilizers used for fertilization. Depletion of nitrogen from wood and other substrate components is referred to as nitrogen removal, which requires additional N in the form of controlled-release fertilizers (Handreck, Black, 2010). The researchers indicate that nitrogen requirements are low early in the growth cycle and increase rapidly from 36 days after germination, with other nutrients being used similarly. Nitrogen contained in organic substrates is considered an important source of it, but it is not always available to plants due to the biological processes in them. Nitrogen in organic media is mineralized, providing many soluble organic N compounds that are taken up either by microorganisms living in the growing media or by plants (Burnett et al., 2016; Dion et al., 2020). There is a lack of research on the availability of nutrients from the growing media and its influence on productivity and fruit quality. The immobilization of nitrogen supplied to plants in the substrate solution, and the consequent degradation and shrinkage of the media, is a major problem in wood substrates, which may be related to the proportions and possible interactions between the polysaccharides and lignin in these materials. In contrast to peat, coconut fiber, and bark, wood-based materials have a lower lignin content and, according to Domeno et al. (2010), a very high concentration of hemicellulose. The latter polysaccharides can be readily degraded in wood substrates, especially those with small particle sizes such as sawdust, fine wood fibers, and finely ground wood substrates. Such substrates have a large surface area for microbial colonization, but due to the immobilization that takes place there, additional nitrogen is required.

RESEARCH METHODS

The experiment was conducted at Vytautas Magnus University Agriculture Academy, Joint Research Centre of Agriculture and Forestry in a regulated-climate greenhouse and the Soil and Crop Ecology Laboratory of Experimental Station in 2021. The cucumbers selected for the experiment with different growing media under controlled climate conditions were common short cucumbers (*Cucumis sativus* L.) Cucumber seedlings were grown from seed in a climate-controlled chamber, RUMED1303. The temperature of the germination chamber was 25 °C and the humidity was 80%. The nursery was filled with peat substrate for seed germination. As the seedlings produced their second true leaf, they were transferred to the greenhouse and planted in 5-liter plastic growing containers filled with the test growing media. Four growing media (four treatments of the experiment (factor A)) were studied: 1) 100% peat substrate (PS) (control substrate); 2) 100% wood fiber (WF); 3) 50/50 wood fiber/peat by volume (WF/PS 50/50); and 4) 25/75 wood fiber/peat by volume (WF/PS 25/75). Both mixtures of wood fiber and peat were prepared just before the start of the experiment. Each treatment of the growing media was divided into four groups of four fertilization backgrounds (factor B): 1) conventional fertilization (control); 2) N_{13} as an additional fertilization; 3) N_{23} as an additional fertilization; and 4) N_{30} as an additional fertilization.

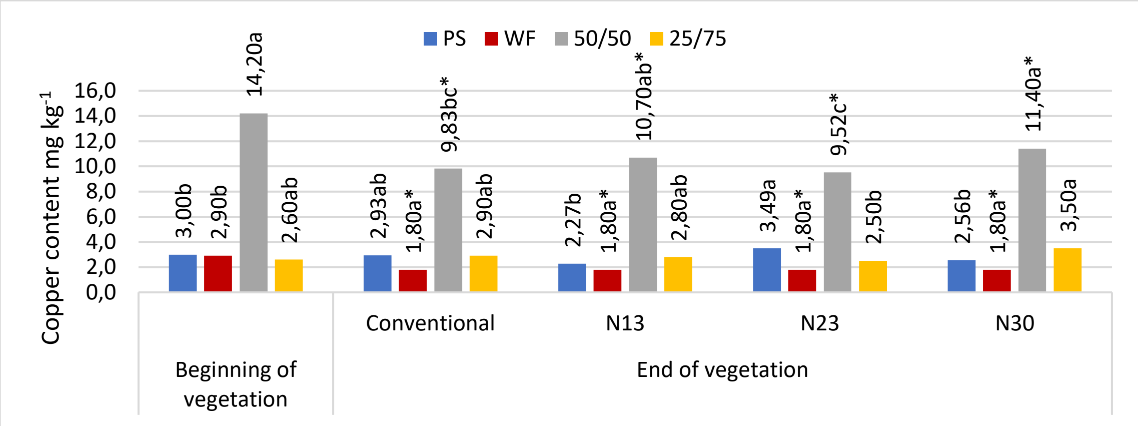
In the experiment, conventional fertilization was carried out with the mineral fertilizer YaraMila® COMPLEX NPK 12-11-18 with microelements. This complex fertilizer contains all the essential nutrients needed for the plants. The chemical composition of the fertilizer is as follows: nitrogen (N): 12%, phosphorus (P_2O_5/P): 11/4.8%, potassium (K_2O/K): 18/14.9%, magnesium (MgO/Mg): 2.7/1.8%, sulfur (SO^{3-}/S): 20/8%, boron (B): 0.015%, iron (Fe): 0.20%, manganese (Mn): 0.02%, and zinc (Zn): 0.02%. 1.60 kg of complex fertilizer was dissolved in 1 m^3 of water. Until flowering, the cucumbers were fertilized once a week with 500 ml of the nutrient solution per plant. Cucumbers were fertilized twice a week with this fertilizer during the growing season. For additional nitrogen fertilization, water-soluble calcium nitrate ($Ca(NO_3)_2$) was used. The chemical composition of the fertilizer was as follows: total nitrogen (N) – 15.5% (nitrate nitrogen (N-NO_3) – 14.4%), ammonia nitrogen (N-NH_4) – 1.1%), and calcium oxide (CaO) – 26.3% (calcium – 18.8%). Calcium nitrate was applied once a week (11 times every 7 days) to the plants during the growing season to provide them with the additional nitrogen required in the experiment.

Copper (Cu) and zinc (Zn) contents were determined according to EN 13650:2003 and EN 8288:2002. Magnesium (Mg) and total iron (Fe) were determined according to EN 13650:2003, AOAC 974.27. Chemical analysis of nutrients carried out at the Agrochemical Research Laboratory of the Lithuanian Research Centre for Agriculture and Forestry. All nutrients were determined in three replications.

All data were statistically analyzed using the computer program package STATISTICA10 by the method of two-way (growing media × fertilization) analysis of variance (ANOVA). Statistically significant differences in data were determined by Fisher's criterion and the least significant difference (LSD) test at the probability level of 95% ($p \leqslant 0.05$).

RESEARCH RESULTS AND DISCUSSION

At the beginning and the end of the cucumber growing season, the amount of trace elements in the growing media was determined to assess how the amount of trace elements depended on plant fertilization with different nitrogen rates. Comparison of the copper content in all media at all fertilization rates showed that at the end of the growing season, the wood fiber contained significantly less copper, by as much as 99%, and the 50/50 growing media contained significantly more copper than the peat substrate under background fertilization (control) (Figure 1).

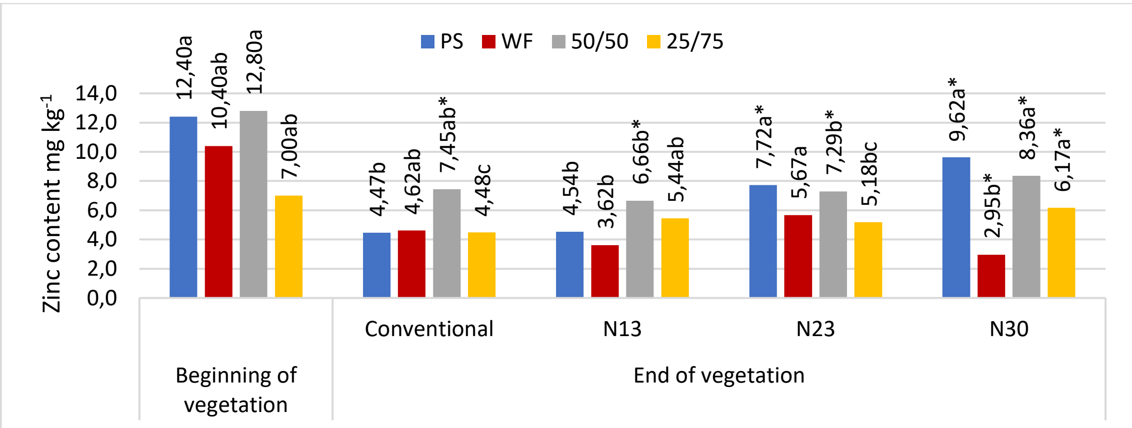


Note: PS – peat substrate; WF – wood fiber; WF/PS 50/50 – a mixture of wood fiber and peat substrate 50:50 v/v; WF/PS 25/75 – a mixture of wood fiber and peat substrate 25:75 v/v. Values marked with * in the columns are significantly different from the control (peat substrate, conventional fertilization). Values marked with different letters (a, b...) in media are significantly different between nitrogen fertilization rates, *P*<0.05.

Figure 1. The influence of additional nitrogen fertilization on the variation of copper content in the growing media during the cucumber growing season

The copper content of the 25/75 growing media and the peat substrate at different fertilization rates did not differ from that of the peat substrate under background fertilization (control). Plants grown in wood fiber with different nitrogen fertilization rates absorbed the same amount of copper during the growing season. Cucumbers grown in the peat substrate fertilized with N_{23} retained significantly more copper in the media than cucumbers grown in N_{13} and N_{30}. In the 50/50 and 25/75 wood fiber growing media, plants fertilized with N_{23} had the highest copper uptake. In these media, the zinc content remained significantly lower, 17% and 29%, respectively, than in the media with N_{30} nitrogen.

The variation of zinc content in the growing media was influenced by the fertilization with different nitrogen rates (Figure 2).

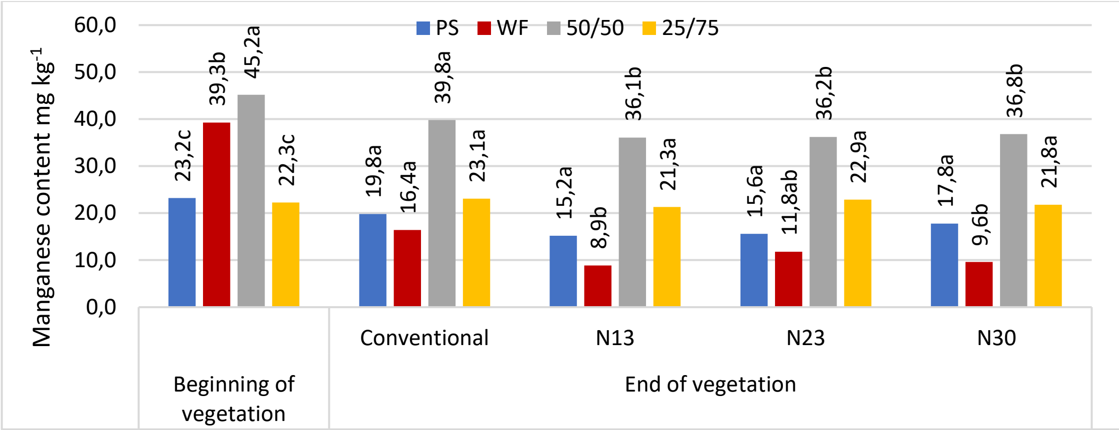


Note: PS – peat substrate; WF – wood fiber; WF/PS 50/50 – a mixture of wood fiber and peat substrate 50:50 v/v; WF/PS 25/75 – a mixture of wood fiber and peat substrate 25:75 v/v. Values marked with * in the columns are significantly different from the control (peat substrate, conventional fertilization). Values marked with different letters (a, b...) in media are significantly different between nitrogen fertilization rates, *P*<0.05.

Figure 2. The influence of additional nitrogen fertilization on the variation of zinc content in the growing media during the cucumber growing season

The highest zinc content was found in the peat substrate with N_{23} and N_{30} fertilization, in the 50/50 growing media with all fertilization treatments, and in the 25/75 growing media with N_{30} fertilization. Plants grown on wood fiber media with N_{30} fertilizer had a significant zinc residue at the end of the growing season, 34% less than the zinc content of the peat substrate with background fertilization (control). The peat substrate, when fertilized with N_{23} and N_{30}, retained significantly more zinc than the substrate with background fertilization and N_{13}. Cucumbers grown on wood fiber had the best uptake of zinc at the highest nitrogen rate of N_{30}. In this media, zinc uptake was significantly, 48% lower than in the wood fiber with N_{23}. In the 50/50 and 25/75 growing media, as in the peat substrate, zinc uptake was worst in the plants fertilized with the highest rate of N_{30}. In these media, 15 and 19% more zinc was detected compared to N_{23} fertilization.

Nitrogen immobilization and different rates of nitrogen applied to the plants did not affect the manganese content of the peat substrate and the growing media 25/75, although an increase in nitrogen tended to improve the uptake of manganese (Figure 3).

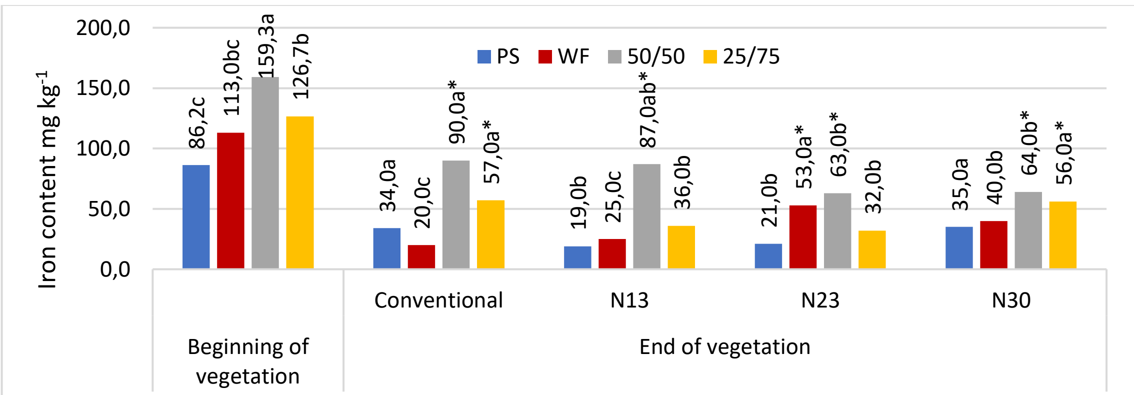


Note: PS – peat substrate; WF – wood fiber; WF/PS 50/50 – a mixture of wood fiber and peat substrate 50:50 v/v; WF/PS 25/75 – a mixture of wood fiber and peat substrate 25:75 v/v. Values marked with * in the columns are significantly different from the control (peat substrate, conventional fertilization). Values marked with different letters (a, b...) in media are significantly different between nitrogen fertilization rates *P*<0.05.

Figure 3. The influence of additional nitrogen fertilization on the variation of manganese content in the growing media during the cucumber growing season

Cucumbers grown in wood fiber fertilized with N_{13}, N_{23}, and N_{30} had the lowest manganese content of all the media, 8.9 to 11.8 mg kg^{-1} which was on average 38% lower than the manganese content of the wood fiber fertilized with background fertilizer. A very similar effect of nitrogen immobilization and fertilization with different nitrogen rates was found in the 50/50 growing media. The manganese content of the growing media was significantly, on average 9%, lower than the manganese content of the media with background fertilization at the end of the growing season when the plants were fertilized with additional nitrogen.

The variation in iron content during the growing season in the growing media was influenced by the fertilization with different nitrogen rates (Figure 4). The highest iron content was found in the wood fiber when the plants were fertilized with N_{23}, in the 50/50 media with all four fertilizers studied, and in the 25/75 media with background and N_{30} fertilization. Here, the iron content was significantly higher than in the peat substrate where the plants were fertilized with background fertilizer (control). The iron content of the media increased significantly when the nitrogen content was increased to N_{23} and N_{30} for the plants grown in the wood fiber. It was twice as high as the iron content in the wood fiber with N_{13} fertilization and 32% higher than the iron content in the wood fiber with N_{30} fertilization. In the 50/50 media, the application of N_{23} and N_{30} significantly reduced the iron content. Therefore, the iron content was 30 and 29% lower, respectively, then in the media where the plants were treated with background fertilizer. Thus, in this media, the uptake of iron is significantly improved when the plants are grown with elevated nitrogen content. In media 25/75, as in the peat substrate, the iron content decreased significantly when the plants were fertilized with N_{13} and N_{23}, while the highest nitrogen content of N_{30} increased the content of this trace element in these media at the end of the growing season. Excessive nitrogen interfered with iron uptake by the plants.



Note: PS – peat substrate; WF – wood fiber; WF/PS 50/50 – a mixture of wood fiber and peat substrate 50:50 v/v; WF/PS 25/75 – a mixture of wood fiber and peat substrate 25:75 v/v. Values marked with * in the columns are significantly different from the control (peat substrate, conventional fertilization). Values marked with different letters (a, b...) in media are significantly different between nitrogen fertilization rates, *P*<0.05.

Figure 4. The influence of additional nitrogen fertilization on the variation of iron content in the growing media during the cucumber growing season

Cucumbers need nutrients but are very sensitive to excess nutrients or sudden changes in concentration in the growing media. In organic growing media, nutrients may be blocked by microorganisms, but studies have shown that cucumbers grown in perlite had poorer growth in both the vegetative and reproductive phases compared to organic media: the leaves showed signs of nutritional deficiency, the smallest green and dry mass of the vegetative part, and a poorer yield. Scientists explain that this phenomenon is due to an indirect effect of the substrates in terms of nutrient retention and availability (Gruda and Schnitzler, 2001 and 2004; Ayipio et al., 2021; Zawadzińska, 2021). When C sources are abundant in the media, large amounts of N can be immobilized in the microbial biomass of the media (Jones et al., 2005). The N content in the wood fiber-based media varied. Urea fertilization resulted in faster N release than fertilizers made from cattle hooves and horns. The latter are degraded more slowly by microorganisms in the wood fiber (Carlile et al., 2019). The research was carried out to develop a high-quality growing media mixture consisting of 30% peat, 40% woody material, and 30% bark compost. Compared to conventional green or vegetable, fruit, and garden waste composts, the woody composts were more suitable for use in growing media due to their lower pH, EC, and inorganic C content, but the woody compost had a low mineralization rate. The three combination types of compost supported higher microbial biomass than wood fiber or bark compost (Vandecasteele et al., 2022). Our study showed that more plant-available N was available in the media when the additional N content was increased to N_{23} and N_{30}. In the wood fiber media, all additional nitrogen immobilization to compensate for and accelerate the destruction of the wood fiber significantly increased the N_{min}. compared to conventional fertilization alone. Results from a study by Yang et al. (2022) showed that wood fiber removed the highest amount of N from the cycle throughout the growing season but removed lower amounts of other types of nutrients than other organic substrates. Increasing the rate to N_{30} did not reduce the content of Zn and Cu in the growing media during the growing season, but the high N rate reduced the Fe content. It can be assumed that the additional fertilization with a higher N rate on the peat substrate and on the media with wood fiber hindered the uptake of Zn and Cu. Scientists indicate that Cu and Mg uptake is directly dependent on Zn content and can be related to soil N supply, given that as Zn content increases, so do Cu and Mg content, and that the effect on plant metabolism leads to an increase in the uptake of nutrients (Mills, et al., 1996). In mixed media, manganese and iron uptake by plants was better when fertilized with elevated nitrogen rates (N_{23} and N_{30}), while in peat substrates it was better when fertilized with the lowest rate of N_{13}. Plants grown on a 50/50 split between peat and wood fiber had the best uptake of Mg and Fe when fertilized with N_{23}. De Mesquita et al., (2022) indicate that N fertilization promoted the proper nutrition of the micronutrients Ca, Mg, B, Cu, Mn, and Zn in zucchinis which was associated with the utilization of silicon, which also led to an improvement in the quality of fruit. In the 50/50 growth media with N_{13}, more iron was retained than when the nitrogen rate was increased to N_{23} or N_{30}. In the peat substrate and the mixture with higher peat content (25/75), the higher nitrogen application reduced the amount of iron available to cucumbers. Cucumbers absorbed iron better from the peat substrate than from pure wood fiber and mixtures with wood fiber.

CONCLUSIONS

Different levels of additional nitrogen had different effects on nutrient uptake. Plants grown in 50/50 and 25/75 growing media had the best copper uptake when fertilized with N_{23}, while the uptake of copper by plants grown in the wood fiber was not affected by nitrogen fertilization. When the plants grown in the wood fiber and in the 50/50 media were fertilized with additional N_{13}, N_{23} and N_{30}, the manganese content of the growing media at the end of the growing season was significantly lower than the manganese content of the media where the plants received conventional fertilization. Thus, additional nitrogen improved the uptake of manganese by plants grown not only in the wood fiber, but also in combination with peat substrate. Growing the plants in the wood fiber and fertilizing them with a additional N_{23}-nitrogen can achieve optimum nutrient uptake in cucumbers.

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