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Case Study Open Access

Case Study on Nutrient-Enriched Sweet Potato Varieties: Breeding and Agronomic Performance

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Abstract Sweet potato (*Ipomoea batatas*), as a versatile crop, has become an important food source in many resource-deficient areas due to its high yield and good storage stability. This study reviewed the breeding technology and agronomic performance of nutrient-rich sweet potato varieties, and explored the potential and application of biofortified sweet potato in global nutrition improvement; and systematically reviewed the main breeding methods for enhancing the nutritional value of sweet potato, including genetic engineering and traditional breeding techniques, as well as the role of these technologies in improving the vitamin A, antioxidant and mineral content of sweet potato. Combined with actual cases, this study aims to provide strategies for future breeding programs and facilitate the development and promotion of nutritionally fortified crops.

Keywords Nutrient-enriched sweet potato; Orange-fleshed sweet potato (OFSP); Biofortification; Agronomic performance; Vitamin A deficiency

1 Introduction

To be honest, it's a complicated matter to address micronutrient deficiencies, but biofortification is a good idea (Garg et al., 2018). This may be especially useful in places where people cannot afford to eat a diverse diet. However, both traditional breeding and genetic modification can be used, and the key is to increase the vitamin and mineral content of crops (Kumar et al., 2022). In Africa, orange sweet potatoes are really helpful because of their high vitamin A content (Laurie et al., 2015). Of course, it's not suitable for all places, but examples like iron-fortified beans and zinc-enriched rice (Dhaliwal et al., 2022) do show that biofortification can play a significant role in fighting hidden hunger.

Sweet potatoes (*Ipomoea batatas*) are interesting. You may not know that they are life-saving food in many places. They are high-yielding, easy to grow, and rich in nutrients-especially the orange-fleshed varieties, which are particularly high in beta-carotene (Tanumihardjo et al., 2017). To be honest, in places where agricultural conditions are not good, growing sweet potatoes can indeed help many families solve the problem of food. Of course, not all sweet potatoes are the same, but fortified varieties such as those tested in some African countries have been quite successful (Siwela et al., 2020). Although the effects may vary from region to region, data shows that these new varieties can indeed improve vitamin A deficiency and improve overall nutritional levels (Huey et al., 2022).

This study mainly wants to talk about the biofortified sweet potatoes-how to breed, how to plant, and whether farmers will buy them. To be honest, although the nutrition of these new varieties has improved, it is not so easy to promote them. We have looked up many actual cases and found that some places do have good results and can help improve malnutrition (of course, it depends on how it is implemented). But then again, there are many troubles, such as planting habits and market acceptance. All in all, biofortified sweet potatoes are indeed a way, but to completely solve the problem of food security, we may have to observe further.

2 Breeding Techniques for Sweet Potato Varieties

2.1 Combining traditional breeding methods with modern biotechnology

When it comes to sweet potato breeding, the old methods such as hybridization and selection have always been used a lot, after all, they can select high-yield and disease-resistant varieties (Zhang et al., 2024). However, in

recent years, technological development has indeed brought a lot of new tricks. Gene editing technologies such as CRISPR/Cas9 can now produce enhanced varieties without exogenous genes (Hameed et al., 2018). Of course, traditional methods have not been completely replaced-the combination of the two is even more effective.

In particular, orange-fleshed sweet potatoes have been greatly helped in some African countries after being genetically enhanced with vitamin A content (Garg et al., 2018). Although the planting conditions in different places vary greatly, with the help of genome sequencing technology, it is indeed much faster to find key genes. But then again, the promotion of new technologies always takes time, and practical problems such as farmers' acceptance and planting costs still need to be solved step by step.

2.2 Selection and integration of target nutrients

Sweet potato breeding is actually quite particular-what nutrients to choose for fortification depends on what the local people lack. For example, the orange-fleshed variety (OFSP) has a particularly high content of β-carotene, which is particularly effective in improving vitamin A deficiency. But what's interesting is that although the white-fleshed variety (WFSP) is plain in color, it has a higher carbohydrate content and can provide more energy (Shekhar et al., 2015).

Now the breeding methods have also been upgraded and no longer rely solely on manual screening. New tools such as portable mid-infrared spectroscopy can quickly detect components such as anthocyanins and phenols (Ayvaz et al., 2016), which should also be quite suitable for sweet potato breeding. Of course, different regions have different needs. For example, in some places where children are severely stunted, it is necessary to focus on fortifying iron and zinc (Ojwang' et al., 2023). In the final analysis, it is necessary to make sweet potatoes more nutritious and ensure that they are easy to grow and high-yielding, so that farmers are willing to grow them.

3 Agronomic Performance Evaluation

3.1 Field trial layout and experimental design

Field trials are actually quite laborious-after all, it takes more than one planting to evaluate whether these nutritionally fortified sweet potatoes are effective. We usually use a randomized block design, and we must do multiple replications (Lemma et al., 2023), otherwise the data is simply unreadable. Take orange-fleshed varieties, such as Kabode and Dilla, for example. They must be arranged in a 5×3×2 alpha grid design, with at least three replications for each. But what's interesting is that some varieties perform particularly well under specific conditions. There is also an even more exaggerated experiment that used 95 different germplasms plus 2 commercial control varieties (Vargas et al., 2017), also with three replications. Although the workload is a bit large, this is the only way to see the true agronomic performance of these varieties under different fertilization conditions.

3.2 Growth performance of nutrient-enriched sweet potatoes

Fertilization has a significant impact on sweet potatoes, especially the ratio of nitrogen and phosphorus fertilizers. Take the NASPOT-12 variety for example. It performed best when 23 kg of nitrogen and 46 kg of phosphorus pentoxide per hectare were used (Brouwer et al., 2023)-not only did the yield increase, but the nutrient absorption efficiency was also improved. But what's interesting is that different varieties respond differently. For example, Dilla can harvest more than 23 tons per hectare under optimized management, which is slightly higher than Alamura (Mekonnen, 2021). This shows that if you want a good harvest, it is not enough to just choose the right variety. The fertilizer combination must also be exquisite and the balance point must be found.

When it comes to growing sweet potatoes, disease resistance is key-especially that annoying sweet potato virus disease (SPVD). Interestingly, varieties like Dilla and Alamura (Mekonnen, 2021) are naturally more resistant to diseases, so they grow particularly well. But then again, the variety's own resistance is not enough, and we have found that organic control methods are also very effective against diseases such as sclerotinia (Rempelos et al., 2023). So, in order to cultivate sweet potato varieties that are both nutritious and high-yielding, disease resistance is really a key consideration, after all, pests and diseases directly affect the harvest.

4 Nutritional Value and Health Benefits

4.1 Detailed analysis of nutritional components

Sweet potatoes (*Ipomoea batatas* [L.] Lam) are quite interesting. Different colors and parts have very different nutritional values (Wang et al., 2016). The orange-fleshed ones have a lot of beta-carotene, which is good for the eyes (Alam, 2021); the purple-fleshed ones have a high content of anthocyanins and a strong antioxidant effect; the white-fleshed ones may look ordinary, but they are rich in carbohydrates. When it comes to orange-fleshed varieties, Bangladesh found that the differences between the two varieties, BARI SP8 and SP7, are quite obvious. One has more carotenoids and the other has a high polyphenol content (Alam et al., 2016). The situation in Nigeria is different. The red variety has more protein and the yellow variety has more water (Muhammad et al., 2022), but both contain essential minerals such as potassium and magnesium. So when choosing sweet potatoes, you can't just look at the appearance, you have to see what specific nutrients you need to supplement.

4.2 Health benefits assessment for consumers

There are many benefits of sweet potatoes. Especially the orange-fleshed ones (OFSP), which are high in beta-carotene, which is particularly useful for improving vitamin A deficiency-this is a big problem in many developing countries and can effectively prevent night blindness (Alam, 2021). The purple-fleshed ones are also not bad, with high anthocyanin content, good antioxidant and anti-inflammatory effects, and even anti-cancer (Shekhar et al., 2015). These ingredients are helpful in preventing cardiovascular diseases and so on.

Interestingly, sweet potatoes are also good for controlling blood sugar. Not only is the glycemic index low, but the fiber content is also high. In addition, the phenolic acids and flavonoids in it (Wang et al., 2016) are quite friendly to diabetics. Recent studies have found that it can actually protect the liver (Laveriano-Santos et al., 2022), and it also has good antibacterial effects, which is very beneficial to intestinal health. From this point of view, sweet potatoes are really an all-round player.

5 Environmental Impact Assessment

5.1 Impact of breeding and agronomic practices on ecosystems

When it comes to growing sweet potatoes, it is really important to choose the right variety and planting method. Interestingly, if you use organic methods to grow them, the microorganisms in the soil will become more diverse and the nutrients will be richer (Yang et al., 2019). Compared with chemical fertilizers, organic fertilizers have another advantage-they can reduce harmful metals such as cadmium and nickel in the soil (Sapakhova et al., 2023), which is much more environmentally friendly. Speaking of water conservation, some drought-resistant varieties are now quite powerful and can grow well even in water shortages. The reason why these varieties are drought-resistant is that they have special genetic mechanisms in their bodies. When drought occurs, they can sense signals and then activate the synthesis of some protective proteins, such as LEA and AQP (Figure 1) (Sapakhova et al., 2023). Although the specific mechanism is a bit complicated, in simple terms, it allows sweet potatoes to survive well even in water shortage conditions. So, choosing the right variety and planting it scientifically can not only protect the soil but also save water, killing two birds with one stone.

Planting sweet potatoes is actually quite helpful for agricultural diversity. Think about it, planting different varieties of sweet potatoes together can not only make crops more disease-resistant, but also improve the soil (Yang et al., 2019). Especially the orange-fleshed ones, which are high in vitamin A, are a blessing for people who don’t have access to a variety of foods (Garg et al., 2018). But then again, the selection of varieties also depends on the local conditions. Recently, some new varieties have been specially cultivated for specific environments (Ojwang' et al., 2023), which not only protects genetic resources, but also makes sustainable use of agricultural diversity. In the final analysis, planting sweet potatoes is not only for yield, but also for long-term development.

5.2 Integration of sustainable agricultural practices

If you want to grow sweet potatoes sustainably, water and fertilizer management are indeed the key. Although organic farming is a bit more troublesome, it does not use chemical pesticides and fertilizers, and the crops grown are not only nutritious, but also more friendly to the land (Pacifico and Paris, 2016). There are some interesting drought-resistant varieties now, and they can save a lot of water when combined with scientific water use

(Sapakhova et al., 2023). But this is not enough. Old methods such as crop rotation and the use of organic fertilizers are actually quite effective, which can both nourish the land and save water (Brouwer et al., 2023). In the final analysis, farming still requires a balance, and the best effect is achieved by combining new and old methods.

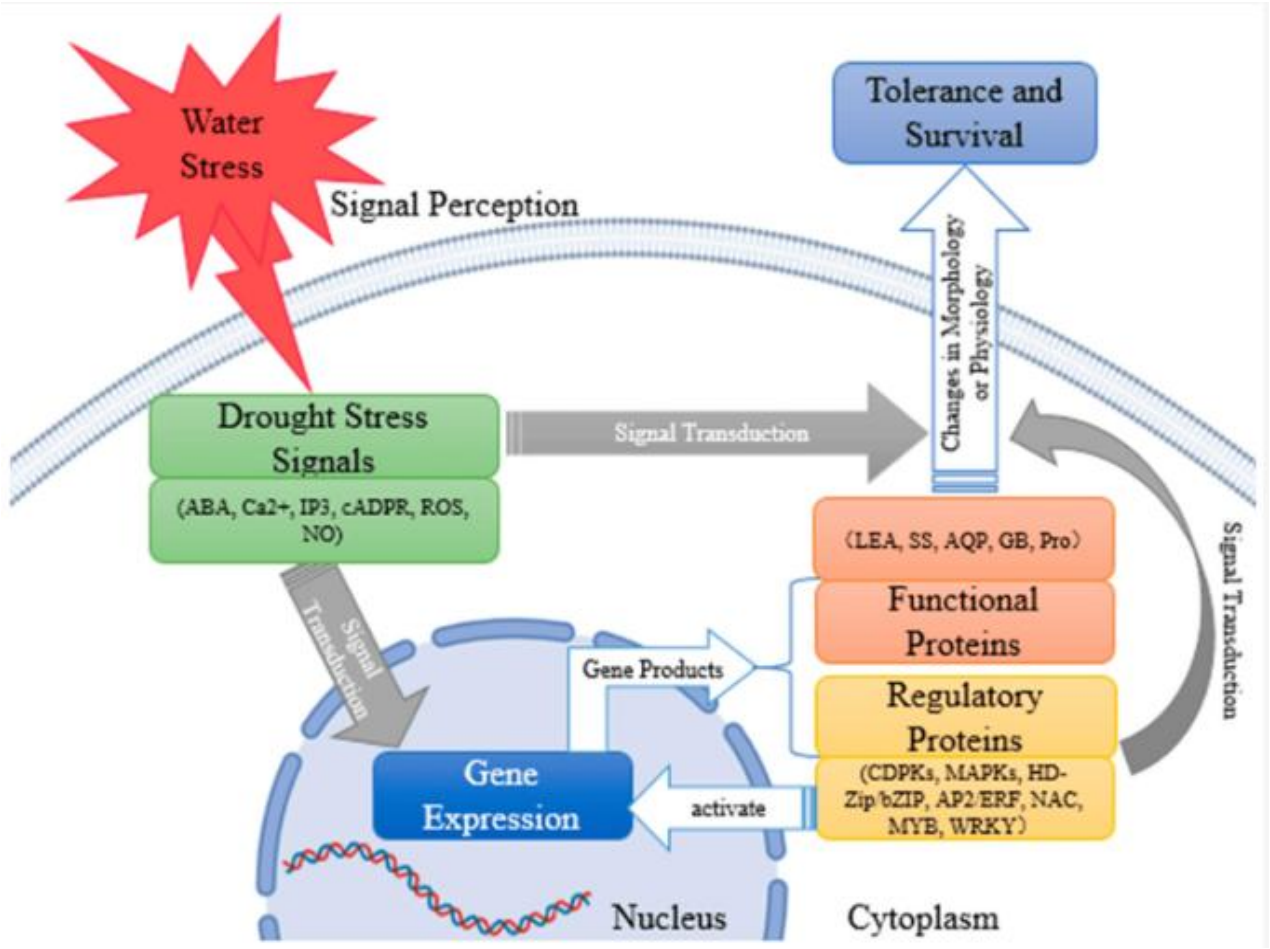

Figure 1 Tolerance mechanism of sweet potato to drought stress (Adopted from Sapakhova et al., 2023)

Organic farmers now know that the best way is to use less fossil fuels, so that the carbon footprint of the crops grown can be much lower (Rempelos et al., 2023). For example, it is very cost-effective to choose biofortified varieties with strong resistance, which use less fertilizers and pesticides and put less pressure on the environment (Garg et al., 2018). But the most amazing thing is that the new technology now combines genomics and breeding, which can make sweet potatoes use nitrogen fertilizer more efficiently (Tiwari et al., 2018). In this way, not only can the fertilizer money be saved, but carbon emissions can also be reduced.

6 Market Performance and Economic Evaluation

6.1 Market acceptance of nutrient-enriched sweet potatoes

The fortified sweet potatoes on the market now, especially the orange-fleshed variety (OFSP), are indeed more popular than ordinary varieties. This is mainly due to their rich beta-carotene content, which is an important source of vitamin A (Alam, 2021; Laurie et al., 2022). Interestingly, varieties such as Bophelo and NASPOT-12 are particularly popular among small vendors, and ordinary people recognize their nutritional value (Lemma et al., 2023).

However, breeding is not a casual thing. Current research is becoming more and more targeted, specifically developing new varieties for specific needs such as poor areas and people with nutritional deficiencies (Leite et al., 2022). In this way, practical problems can be solved and ordinary people are more willing to accept them. In the final analysis, it is this precise breeding method that makes nutritious sweet potatoes more and more popular.

6.2 Economic feasibility analysis

Growing fortified sweet potatoes is indeed economically beneficial-it can solve the problem of food, bring health benefits, and farmers can also make more money. Take the orange-fleshed variety NASPOT-12 for example. Under reasonable fertilization, the yield and nutrient absorption efficiency are outstanding (Lemma et al., 2023). It has low input and high output, which is particularly cost-effective for small farmers.

Now that the climate is becoming more and more unstable, drought-resistant varieties are particularly important. These varieties can ensure stable harvests and reduce the risk of crop failure (Sapakhova et al., 2023). Even if the weather is bad, there is a guaranteed yield. What's more amazing is that molecular breeding technology is now used. Tools such as SSR markers can accurately screen out good varieties with high starch content and high β-carotene (Zhang et al., 2016). In this way, the breeding efficiency is improved, and the sweet potatoes grown are more in line with market demand, so they can naturally sell at a good price.

7 Case Study: Development and Application of Specific Varieties

7.1 Variety selection and background introduction

To put it bluntly, breeding sweet potatoes in developing countries is about solving three problems: feeding people, eating well, and making more money. The people at the international potato center (CIP) are quite good at breeding varieties specifically for the needs of different places (Laurie et al., 2022). They got seeds from places like Mozambique and Uganda, and combined with hybrid breeding technology, they really made a lot of good varieties (Figure 2).

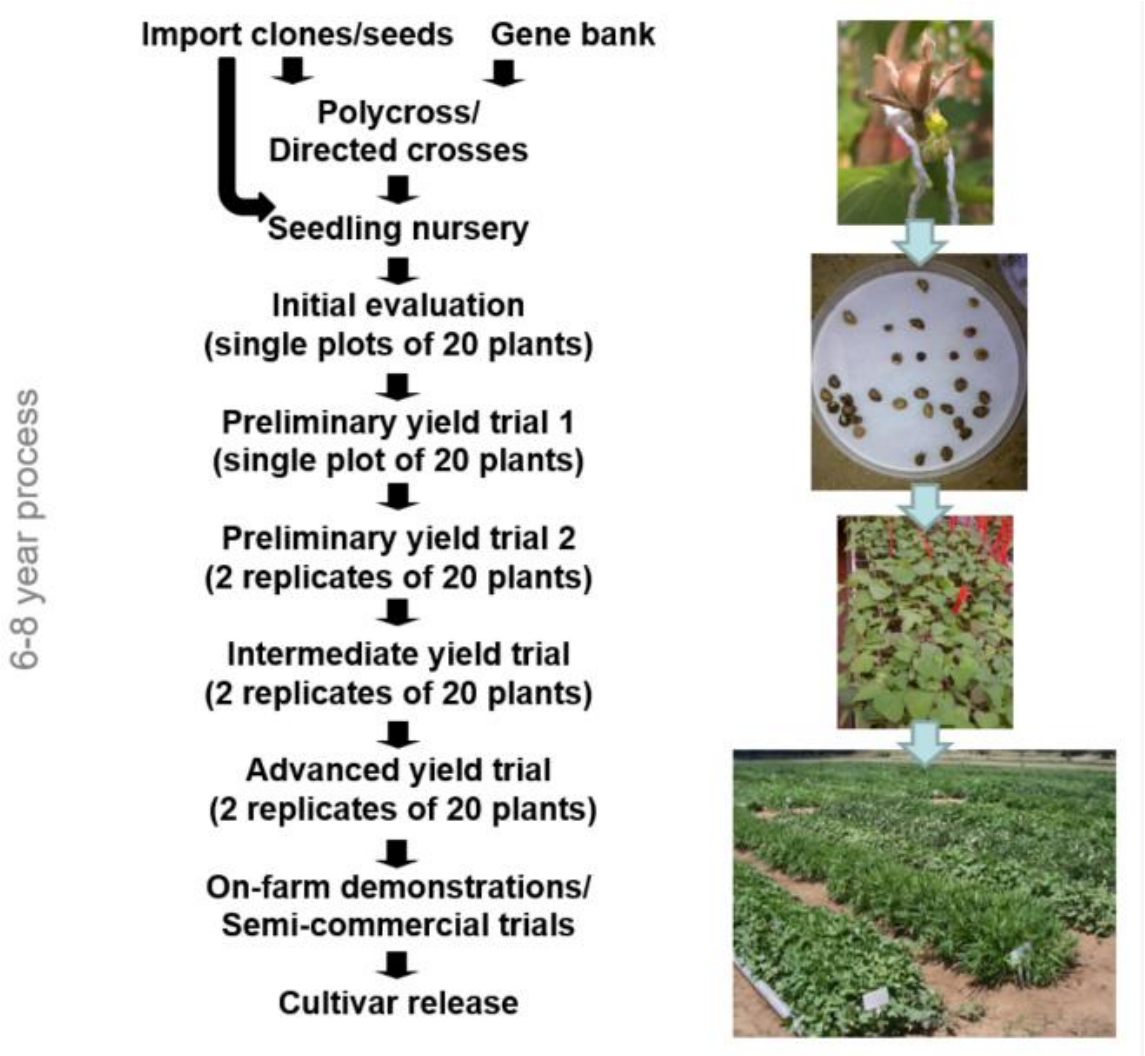

Figure 2 Schematic diagram of the breeding cycle of the polyhybrid method (Adopoted from Laurie et al., 2022)

There is a reason why orange-fleshed sweet potatoes (OFSP) are particularly valued-they have a high content of β-carotene and are particularly effective in preventing vitamin A deficiency (Brouwer et al., 2023). The varieties Bophelo and Ndou promoted in South Africa are good. They are both hunger-resistant and drought-resistant, and farmers can grow them without any worries. But having good varieties is not enough. The key is to make people willing to grow and afford them, so that this thing can be considered a real success.

7.2 Breeding process and technological application

Sweet potato breeding now uses a mixture of traditional methods and new technologies. Interestingly, tools like CropInd (Rosero et al., 2023) can help screen out good varieties that perform stably in different places. However, performance alone is not enough. SSR markers are now used (Zhang et al., 2016), which can accurately find plants with high starch and β-carotene content, greatly improving breeding efficiency. The most eye-catching is gene editing technologies such as CRISPR (Hameed et al., 2018), which can improve varieties without transferring exogenous genes, solving regulatory problems and making them more acceptable to consumers. In the final analysis, breeding is becoming more and more scientific, but the ultimate goal is to grow sweet potatoes that are more delicious and nutritious.

7.3 Agronomic performance and market feedback

What farmers value most when choosing sweet potato varieties is actual performance-whether it can produce high yields, save fertilizers, and sell well. The orange-fleshed NASPOT-12 is a typical example. As long as the nitrogen and phosphorus fertilizers are properly matched, the yield and nutrient absorption are excellent (Lemma et al., 2023). Interestingly, when these varieties were promoted in southern Ethiopia, some dietary education was carried out in conjunction with it, and the effect was surprisingly good, and the people's eating habits improved. Now varieties such as Bophelo and Ndou are particularly popular in the market (Laurie et al., 2022). They are not only nutritious, but also very resistant to drought. Promoting these varieties can not only solve the problem of eating, but also improve malnutrition, which is a two-pronged approach. But in the final analysis, no matter how good the new varieties are, farmers have to be willing to plant them, so actual performance is the hard truth.

8 Global impact of fortified sweet potatoes

8.1 Major findings and the impact of fortification

When studying sweet potato varieties, we found that there are significant nutritional differences between varieties of different colors. Orange-fleshed sweet potatoes (OFSP) are particularly outstanding in this regard, with high levels of nutrients such as vitamin A and flavonoids (Sinkovič et al., 2017). Interestingly, fertilization methods have a great impact on yields-the variety NASPOT-12 performs best under a specific nitrogen and phosphorus fertilizer ratio and has a particularly high nutrient absorption efficiency. However, having good varieties alone is not enough. When we piloted in Ethiopia, we found that the effect would be better if we carried out nutrition knowledge promotion in conjunction with it. After local farmers began to get used to growing and eating these orange-fleshed sweet potatoes, the dietary structure of the entire community improved. This also shows that the most effective way to solve the problem of malnutrition is to work on both variety improvement and dietary habits at the same time.

8.2 Implications for sweet potato breeding and agricultural production

This study really points the way for sweet potato breeding. Look at those orange-fleshed varieties (OFSP), which are not only nutritious, but also perform particularly well under reasonable fertilization conditions (Xiong et al., 2022). This reminds breeders that in the future, when selecting new varieties, they can't just focus on yield, but also take nutritional content into consideration. Interestingly, we found that fertilization is quite particular. The same variety, with different ratios of fertilizers, will eventually grow different quality. This shows that good varieties must be accompanied by scientific planting methods. Combining breeding and agronomic measures can not only ensure yield but also improve nutritional value, which is a win-win choice for sustainable agriculture. But then again, how to operate in each place must be adjusted according to local conditions. After all, agriculture is most about adapting to local conditions.

8.3 Contribution to global food security and improved nutrition

Sweet potato research, especially the orange-fleshed variety (OFSP), has indeed brought new ideas to solving global nutrition problems. Think about it, in places where people cannot afford to eat diversified foods, vitamin A deficiency is a big problem (Zhou and Jiang, 2024). By improving varieties and optimizing planting methods, this seemingly ordinary crop can now provide a lot of key nutrients. The example of southern Ethiopia is very telling-after the promotion of OFSP in the local area, not only the problem of eating has been alleviated, but also the dietary structure and health status have improved. But to be honest, in order for these results to truly benefit more people, we must also consider the planting conditions and eating habits in different regions. After all, no matter how good the variety is, the people must be willing to plant and eat it. In the final analysis, the greatest value of this research may be that it provides a practical solution to improve the problem of global malnutrition.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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