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Provitamin A Crops: Acceptability, Bioavailability, Efficacy and Effectiveness

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ABSTRACT

Vitamin A deficiency (VAD) is the world's commonest cause of childhood blindness. More than half of these cases occur in developing countries. Animal sourced foods though good sources of vitamin A are too expensive for poor rural people. Crops biofortified with provitamin A offer a convenient and accessible source of vitamin A. The other micronutrient programs of fortification and supplementation require more expensive inputs. Biofortification programs have developed crops that are rich in provitamin A. These crops include: maize, golden rice, cassava and orange fleshed sweetpotato (OFSP). With exception of golden rice, the rest of the biofortified crops have received considerable acceptance among the communities. Both animal and human studies have shown that provitamin A from biofortified crops is highly bioavailable and have capacity to improve vitamin A status. After several years of research and promotion, it is time to fully commercialize provitamin A crops by encouraging farmers to start their large scale production and consumption.

Keywords: Biofortification; Provitamin A Crops; Acceptability; Bioavailability

1. Introduction

Vitamin A deficiency (VAD) is the world's commonest cause of childhood blindness. It is estimated that 228 million children are affected sub-clinically and 500,000 children become partially or totally blind every year as a result of VAD [1]. More than half of the cases occur in developing countries and this is attributed to the consumption of vitamin A deficient diets [2]. Animal sourced foods though good sources of vitamin A are too expensive for poor communities to afford [3]. This leaves foods of plant origin as an important source of provitamin A in developing countries.

To combat the prevalence of VAD, scientists have devised various strategies including fortification, supplementation and biofortification [1,4]. Biofortification is the development of micronutrient-dense staple crops using the best traditional breeding practices and modern biotechnology [5]. Biofortification has in particular been encouraged because it has proved to be highly effective in enhancing the provitamin A potential of crops [6,7]. It is considered a new public health approach to control vitamin A, iron, and zinc deficiencies in poor countries. This can be done either through conventional selective breeding, or through genetic engineering. Biofortification differs from ordinary fortification because it focuses on making plant foods more nutritious as the plants are growing, rather than having nutrients added to the foods when they are being processed.

Various staple crops grown in developing have been targeted for biofortification [7]. These include sweetpotatoes, cassava, beans and rice. In all cases traditional methods of breeding have been used except for rice where golden rice was produced using genetic engineering [8]. Despite the benefits of biofortification, there have been challenges in acceptability of biofortified crops and the bioavailability and bioefficacy of the provitamin A has been a question of intense research. This paper intends to evaluate the extent of acceptability, bioavailability and bioefficacy of provitamin A and whether it is time to move on.

2. Acceptability of Provitamin A Crops

During biofortification, there are changes that are intro-

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duced into the staple crops. Apart from enhanced nutrient content, there are usually changes in the colour and taste of the food crops. These changes play a part in whether the biofortified crops are accepted by the intended consumers or not. The acceptability of biofortified crops is affected by several factors discussed below.

2.1. The Method of Breeding

The method of breeding has been one of the issues advanced for communities to reject certain provitamin A crops. Biofortification can be achieved through conventional selective breeding or through genetic engineering However, genetic engineering as a technique for biofortifcation has been maligned and as such some people think that eating crops that are a result of genetic engineering "is like eating a gene". This may explain why golden rice that was developed through genetic engineering has not been fully accepted as a provitamin A crop.

Generally genetic engineered crops have tended to be a "political hot button" and the debate goes on and on. On the other hand, crops that are a result of conventional breeding have found favor within communities on this account. Crops such as orange fleshed sweetpotatoes and biofortified cassava are highly appreciated. This may be partly explained by the involvement of farmers in the breeding process by the local research institutes. In Uganda, there was a heavy involvement of farmers and other stakeholders in the breeding process of orange fleshed sweetpotatoes and consequently, the crop was readily accepted [9]. Likewise, in Nigeria the adoption of biofortified cassava is finding soft ground because the technology used was conventional breeding and stakeholders, especially the farmers were involved in its development.

2.2. Visibility of the Nutrients

The biofortification process changes the colour of the provitamin A crops. Biofortified crops where nutrients are visible as it is the case in provitamin A crops, the colour of the crops becomes a significant consideration. For example, in most countries of Sub-Sahara countries, communities were used to white fleshed sweetpotatoes. The introduction of provitamin A rich orange fleshed sweetpotatoes was initially resisted on the account of the strange orange colour. However, the orange colour was very attractive to children who were the primary target [10]. The colour challenge was compounded by the low dry matter that was associated with orange fleshed sweetpotatoes. Most people in developing countries prefer sweetpotatoes with high dry matter content [11]. In Uganda and elsewhere in Africa, breeders have come up with orange fleshed sweetpotatoes with high dry matter while keeping the targeted amount of provitamin A carotenoids. The colour challenge has also been faced in marketing yellow maize. Biofortification of maize with provitamin A carotenoids changes the grain colour from white to yellow-orange, as well as the aroma and flavor of the maize [12]. Organoleptic studies of yellow maize conducted in eastern and southern Africa have shown that there is a cultural preference for white maize to yellow maize, which seems to be due to the unacceptable sensory properties of the yellow maize [13-15]. Fortunately, recent studies have indicated that yellow, provitamin A-biofortified maize has the potential to succeed as a new strategy of dealing with the serious problem of vitamin A deficiency, especially among children of preschool age [12]. However, in older groups, intensive nutrition education programmes on the nutritional benefits of the maize as well as targeting the market price at which yellow maize is sold will be necessary if yellow maize is to be accepted in these age groups.

2.3. Nutrition Education

Nutrition education has also been cited as an important factor that affects acceptability of biofortified crops [6]. Nutrition education is an important tool in conveying the nutritional and health benefits of biofortified crops. In Uganda, acceptability of orange fleshed sweetpotatoes was achieved partly as a result of adoption that was driven through demand creation by delivering nutrition messages that explained how these orange-fleshed sweetpotato varieties were a good source of vitamin A. Once the mothers had been educated on the importance of vitamin A, they easily adopted the biofortified crop [9]. It is important for communities to be educated and convinced that the change in colour of the crop consumed may result in improved nutrition and health [6]. It is also strategic to identify the appropriate target for these biofortified crops. Usually the women and children are good targets since these products can also be marketed as improved weaning foods.

2.4. Economic Potential

The success of biofortified provitamin A crops will also depend on their economic potential. Farmers will adopt the new varieties as long as there is an assurance that economically they will benefit. In developing countries, the staple crops apart from being sources of food, they also sources of income. A crop that has limited yield does not get allocated substantial acreage in the farm. Besides, if the crop has nutritional potential and limited economic potential, men are likely to abandon such a crop to women. In many developing countries, men do not involve themselves with crops that are not likely to earn them money and yet it is usually men who decide how much land is allocated to which crop. Therefore, increased production of provitamin A crops will occur when communities have accepted to grow biofortified crops to ensure constant supply in the market. The cultivation of provitamin A crops must make economic sense to local farmers and be regarded as a commercial crop. Nutritional improvement at the cost of higher yields will potentially drag the adoption of provitamin A crops. Fortunately, some of the orange fleshed sweetpotato varieties such as NASPOT 10 (*Kabode*) distributed in Uganda, have higher yields than the white fleshed varieties in addition to early maturity [16]. Clearly, apart from provitamin A carotenoids content, the biofortified crops have other traits that are likely to make them a farmer's number one choice.

With the success of the research into creating biofortfied crops, the concern has also been on the cost of biofortified staple crops. Like any other nutrition intervenetion, biofortification involved various costs. The main costs in the biofortification of provitamin A crops relate to the research needed to produce β-carotene rich varieties as well as program implementation [5]. A study showed that the costs associated with the distribution of 500 million vitamin A capsules ranged from US$ 0.5 in Ghana to US$ 2.27 in South Africa [17]. The cost of producing provitamin A crops has to be considered in regard to their potential to reduce VAD and the cost of alternative interventions in form of vitamin A capsule distribution. Studies from developing countries suggest that provitamin A crops can reduce the problem of VAD in a substantial way. A useful tool which appears appropriate to quantify the health costs of micronutrient malnutrition in developing countries is the disability-adjusted life years (DALYs) approach [18]. This implies that DALYS are a measure of the total number of days that are spent in ill-health each year, accounting for both severity of the condition and its duration [19]. Generally for all biofortified crops, the benefits in DALYS saved each year could be achieved at a cost that is lower than that of fortification and supplementation [20].

3. Bioavailability of Provitamin A from Biofortified Crops

Various biofortified crops with targeted levels of micronutrients have been produced. Another key question has been; to what extent are the provitamin A in biofortfied crops bioavailable? Here we examine the progress achieved in the bioavailability of provitamin A carotenoids in various provitamin A crops.

3.1. Orange Fleshed Sweetpotatoes

One of the most successful provitamin A crops is orange fleshed sweetpotato. Breeders have been successful in availing varieties that have adequate amounts of β-carotene (>100 μg/100 g) [16]. Sweetpotato was targeted for biofortification because it is a staple crop in many developing countries [21]. Efforts to biofortify sweetpotato have focused on increasing beta carotene content and improving organoleptic qualities of varieties which are commonly consumed in many areas where vitamin A deficiency is a major concern. It is estimated that the replacement of white-fleshed sweet with orange-fleshed varieties could benefit about 50 million children under 6 years of age who are currently at risk of vitamin A deficiency related diseases [22].

Recent investigations have focused on the bioavailability of β-carotene from OFSP, defined as the fraction of ingested carotenoid available for use in physiologic functions and storage [23]. Due in part to a favorable food matrix, OFSP improved vitamin A status in several human feeding interventions [10,24]. Using stable isotope methodology [25], sweetpotato β-carotene bioconversion was 13.4 μg β-carotene to 1 μg retinol in Bangladeshi men fed a daily snack of 80 g sweetpotato. Liver reserves of South African schoolchildren improved with a daily portion of OFSP fed during school days [10]. After introduction of OFSP into Mozambique, serum retinol concentrations improved in young children [24].

Food and nutrition scientists have also been involved in researching on several parameters that define bioavailability of provitamin A carotenoids. One of the factors that influence the contribution to nutritional status by a provitamin A crop is retention of the β-carotene following processing and cooking. HarvestPlus has commissioned several studies to study β-carotene retention values in orange fleshed sweetpotatoes [26]. True retention of β-carotene medium sized orange fleshed sweetpotato, Resisto variety was 88% - 92% for medium sized roots of similar size and 70% - 80% when roots of different sizes were boiled together. Thus it has been concluded that orange fleshed sweetpotato varieties with β-carotene content above 100 μg/g have retention values that can influence the nutritional status of deficient individuals [27]. Recent studies in Mongolian gerbils also demonstrated that β-carotene from OFSP had higher bioconversion factors than β-carotene supplements [28]. The various studies have confirmed that OFSP has potential to combat the raging problem of VAD in developing countries.

3.2. Golden Rice

Golden rice is a variety of *Oryza sativa* rice produced through genetic engineering to biosynthesize beta-carotene, a precursor of vitamin A, in the edible parts of rice. Golden Rice has been genetically engineered to contain a high content of β-carotene which is a provitamin A carotenoid. It was first developed by scientists at the Swiss Federal Institute of Technology and the University of

Freiburg. The scientists were able to engineer an entire biosynthetic pathway, making it a major breakthrough in the biotechnology world [29]. This work triggered further research that has resulted into golden rice with more β-carotene than the original golden rice [30]. Further nutrition research has proved that golden rice has potential to provide the daily required amount of vitamin A. In a study in Hunan province of China among children 6 - 8 years, it was shown that the β-carotene in golden rice is as effective as pure β-carotene in oil and better than that in spinach at providing vitamin A to the children [31]. The researchers were able to show that a bowl of approximately 100 to 150 g cooked golden rice (50 g dry weight) can provide about 60% of the Chinese Recommended Nutrient Intake of vitamin A for 6 - 8 year-old children. Earlier on, a study to determine the vitamin A equivalency of Golden Rice β-carotene, established that β-carotene derived from Golden Rice is effectively converted to vitamin A in humans [32]. Despite availability of the evidence that golden rice is a potent strategy to fight vitamin A deficiency, it has met resistance from agencies that are against the use of genetically modified organisms' technologies. Generally, there is a pattern of genetically modified organisms (GMOs) encountering significantly more political resistance than conventionally bred crops [33]. However, there are indications that with continued nutrition education of the people concerning the immense health and nutrition benefits of golden rice, this situation will soon change.

3.3. Biofortified Maize

Maize is an important food crop in many developing countries especially those in Sub-Sahara Africa. In many Eastern and Southern African countries, per capita consumption of maize averages >100 kg per year [34]. Considering, the vast population depending on maize as a staple crop, there have been efforts to increase its nutriational quality**.** Maize has been targeted for biofortification for decades as scientists tried to improve the protein quality [35]. Earlier attempts at biofortification resulted in high quality maize that has been important in meeting the protein demand in communities where it is consumed. Current efforts in biofortification of maize are aimed at increasing the provitamin A content of maize as a food based strategy to fight vitamin A deficiency that is ubiquitous in maize consuming areas [36]. The efforts to biofortify maize with provitamin A carotenoids have largely been successful. In a recent study in Zimbabwe, 8 healthy men were fed 300 g cooked biofortified yellow maize containing 1.2 mg β-carotene that was consumed with 20.5 g fat [37]. The researchers in this study concluded that the experimental diet showed the same vitamin A activity as 0.38 mg retinol and provided 30% - 40% of the adult vitamin A Recommended Dietary Allowance. In another study, six healthy women were fed β-carotene biofortified maize porridge and it was observed that β-carotene in biofortified maize has good bioavailability as a plant source of vitamin A [38]. Earlier studies in animal models had shown that β-carotene from biofortified maize is highly bioavailable [39,40]. Therefore, it can be concluded that there is overwhelming evidence suggesting that β-carotene in biofortified maize is highly bioavailable.

3.4. Biofortfied Cassava

Cassava (*Manihot esculenta*) is an important staple crop in Sub-Sahara Africa. The crop serves as a primary caloric source for many African communities in countries such as Nigeria, Ghana and Uganda. However, frequent consumers of cassava in rural areas are at risk of vitamin A deficiency and other nutritional deficiencies. Because of the aforementioned, cassava is one of the crops that have been selected for biofortification with β-carotene [5,6]. The breeding target for beta-carotene in cassava of 15 μg per gram of fresh root which corresponds about to 45 μg beta-carotene per gram of dry root has been achieved. However, like other biofortified crops, the concern has been the bioavailability of β-carotene in biofortified cassava. β-carotene retention and bioaccessibility in various biofortified cassava varieties have been determined using African traditional cassava processing techniques [41]. This study showed that β-carotene retention in biofortified cassava is sufficient to supply adequate vitamin A requirements. Recent studies further indicate that biofortified cassava can be a good source of β-Carotene and vitamin A [42-44]. The studies on biofortified cassava are not as advanced as in orange fleshed sweetpotatoes and maize but the available information so far points to sufficient amounts of β-carotene retention as well as bioavailability.

4. Conclusion

Provitamin A crops have so far proved to be an effective tool in turning the tide against the scourge of vitamin A deficiency. For several years now, a lot of resources have gone into research aimed at biofortifying the identified crops for provitamin A potential. The targeted levels of provitamin A carotenoids have been achieved. In all the crops, studies have showed that bioavailability/bio-conversion of the provitamin A is high enough to influence the nutritional status of individuals with vitamin A deficiency. Acceptability of the biofortified crops varies from crop to crop but it appears the orange fleshed sweetpotato is ahead of the other provitamin A crops. This may be explained by the level of investments that have been used on sweetpotato biofortification and the breeding method used. The breeding process tended to involve local farmers and this seems to have influenced the acceptability of orange fleshed sweetpotato. Vitamin A cassava and biofortified maize have also been well received in targeted countries. Therefore, scientists have done their part by availing provitamin A crops with levels of β-carotene that are sufficient to supply adequate daily vitamin A requirements for different age groups. The remaining task is for scientists to team up with other stakeholders such as policy makers and politicians to streamline and mainstream the production and consumption of provitamin A crops to eradicate vitamin A deficiency.

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REFERENCES

[1] WHO/FAO, "Diet, Nutrition and the Prevention of Chronic Diseases," Report of the Joint WHO/FAO Expert Consultation, WHO Technical Report Series, WHO, Geneva, 2003.

[2] V. Diaz, E. Hedren, J. Rueles and U. Svernberg, "Effect of Cell Wall Degrading Enzymes on *in Vitro* Carotene Bioaccessibility in Lactic Acid Fermented Carrot Beverage," *Journal of Food Science*, Vol. 69, No. 2, 2004, pp. 136-142.

[3] H. van den Berg, R. Faulks, H. F. Granado, J. Hirschberg, B. Olmedilla, G. Sandman and W. Stahl, "The Potential for the Improvement of Carotenoid Levels in Foods and the Likely Systemic Effects," *Journal of the Science of Food and Agriculture*, Vol.80, No. 7, 2000, pp. 880-912. doi:10.1002/(SICI)1097-0010(20000515)80:7<880::AID-JSFA646>3.0.CO;2-1

[4] C. Hotz and C. McClafferty, "From Harvest to Health: Challenges for Developing Biofortified Staple Foods and Determining Their Impact on Micronutrient Status," *Food and Nutrition Bulletin*, Vol. 28, No. 2, 2007, pp. 1776-1783.

[5] P. Nestel, H. E. Bouis, J. V. Meenakshi and W. Pfeiffer, "Biofortification of Staple Food Crops," *Journal of Nutrition*, Vol. 136, No. 4, 2006, pp. 1064-1067.

[6] S. A. Tanumihardjo, "Food-Based Approaches for Ensuring Adequate Vitamin A Nutrition," *Comprehansive Reviews in Food Science and Food Safety*, Vol. 7, No. 4, 2008, pp. 373-381.

[7] S. A. Tanumihardjo, H. Bouis, C. Hotz, J. V. Meenakshi and B. McClafferty, "Biofortification of Staple Crops: An Emerging Strategy to Combat Hidden Hunger," *Comprehansive Reviews in Food Science and Food Safety*, Vol. 7, No. 4, 2008, pp. 329-334.

[8] K. Yonekura-Sakakibara and K. Saito, "Review: Genetically Modified Plants for the Promotion of Human Health," *Biotechnology Letters*, Vol. 28, No. 24, 2006, pp. 1983-1991. doi:10.1007/s10529-006-9194-4

[9] S. Chowdhury, J. V. Meenashi, K. I. Tomlins and C. Owori, "Are Consumers in Developing Countries Willing to Pay More for Micronutrient-Dense Biofortified Foods? Evidence from a Field Experiment in Uganda," *American Journal Agricultural Economics*, Vol. 93, No. 1, 2011, pp. 83-97.

[10] P. J. van Jaarsveld, M. Faber, S. A. Tannumihardjo, P. Nestel, J. C. Lombard and A. J. S. Benade, "β-Carotene-Rich Orange Fleshed Sweet Potatoes Improve the Vitamin A Status of Primary School Children Assessed with the Modified-Relative-Dose-Response Test," *American Journal of Clinical Nutrition*, Vol. 81, No. 5, 2005, pp. 1080- 1087.

[11] L. Low, P. Kinyae, S. Gichuki, M. A. Oyunga, V. Hagenimana and J. Kabira, "Combating Vitamin A Deficiency through the Use of Sweet Potato," CIP, Lima, 1997.

[12] K. Pillary, J. Derera, M. Siwela and F. J. Veldman, "Consumer Acceptance of Yellow, Provitamin A-Biofortified Maize in KwaZulu-Natal," *South African Journal of Clinical Nutrition*, Vol. 24, No. 4, 2011, pp. 186-191.

[13] R. Stevens and A. Winter-Nelson, "Consumer Acceptance of Pro-Vitamin A-Biofortified Maize in Maputo, Mozambique," *Food Policy*, Vol. 33, No. 4, 2008, pp. 341-351.

[14] T. Muzhingi, A. S. Langyintuo, L. C. Malaba and M. Banziger, "Consumer Acceptability of Yellow Maize Products in Zimbabwe," *Food Policy*, Vol. 33, No. 4, 2008, pp. 352-361. doi:10.1016/j.foodpol.2007.09.003

[15] H. De Groote and S. C. Kimenju, "Comparing Consumer Preferences for Color and Nutritional Quality in Maize: Application of a Semi-Double Bound Logistic Model on Urban Consumers in Kenya," *Food Policy*, Vol. 33, No. 4, 2008, pp. 362-270. doi:10.1016/j.foodpol.2008.02.005

[16] R. O. M. Mwanga, B. Odongo, C. Niringiye and A. Alajo, "Release of Two Orange-Fleshed Sweet Potato Cultivars, 'SPK004' ('Kakamega') and 'Ejumula', in Uganda," *HortScience*, Vol. 42, No. 7, 2007, pp. 1728-1730.

[17] O. Neidecker-Gonzales, P. Nestel and H. Bouis, "Estimating the Global Costs of Vitamin A Capsule Supplementation: A Review of the Literature," *Food and Nutrition Bulletin*, Vol. 28, No. 3, 2007, pp. 307-316.

[18] J. V. Meenakshi, N. Johnson, V. M. Manyong, H. DeGroote, J. Javelosa, D. Yanggen and E. Meng, "How Cost Effective Is Biofortification in Combating Micronutrient Malnutrition? An Exante Assessment," Harvest Plus Working Paper No. 2, Wasgington DC, 2007.

[19] Q. Matin, S. Alexander and J. V. Meenakshi, "Economics of Biofortification," *Agricultural Economics*, Vol. 37, No. 1, 2007, pp. 119-133.

[20] J. V. Meenakshi, N. Johnson, V. Manyong, H. DeGroote, J. Javelosa, D. Yanggen, F. Naher, C. Gonzales, J.Garcia and E. Meng, "How Cost-Effective Is Biofortification in Combating Micronutrient Malnutrition? An Exante Assessment," *World Development*, Vol. 38 No. 1, 2010, pp. 64-75. doi:10.1016/j.worlddev.2009.03.014

[21] A. C. BovellBenjamin and L. T. Steve, "Sweetpotato: A Review of Its Past Present and Future Role in Human Nutrition," *Advances in Food Nutrition Research*, Vol. 52, 2007, pp. 1-59. doi:10.1016/S1043-4526(06)52001-7

[22] P. J. van Jaarsveld, M. De Wet, E. Harmse, P. Nestel and D. B. Rodriguez-Amaya, "Retention of B-Carotene in Boiled, Mashed Orange-Fleshed Sweet Potato," *Journal of Food Composition and Analysis*, Vol. 19 No. 4, 2006, pp. 321-329. doi:10.1016/j.jfca.2004.10.007

[23] S. A.Tanumihardjo, "Factors Influencing the Conversion of Carotenoids to Retinol: Bioavailability to Conversion to Bioefficacy," *International Journal of Vitamin Research*, Vol. 72, No. 1, 2002, pp. 40-45. doi:10.1024/0300-9831.72.1.40

[24] J. Low, M. Arimond, N. Osman, B. Cunguara, B. Zano and D. Tschirley, "A Food-Based Approach Introducing Orange-Fleshed Sweet Potatoes Increased Vitamin A Intake and Serum Retinol Concentrations in Young Children in Rural Mozambique," *The Journal of Nutrition*, Vol. 137, No. 5, 2007, pp. 1320-1327.

[25] M. J. Haskell, K. M. Jamil, F. Hassan, J. M. Peerson, M. I. Hossain, G. J. Fuchs and K. H. Brown, "Daily Consumption of Indian Spinach (*Basella alba*) or Sweet Potatoes Has a Positive Effect on Total Body Vitamin A Stores in Bangladesh Men," *American Journal of Clinical Nutrition*, Vol. 80, No. 3, 2004, pp. 705-714.

[26] E. Boy and A. Miloff, "Provitamin A Carotenoid Retention in Orange Sweetpotato," *Sight and Life Magazine*, No. 3, 2009, pp. 27-33.

[27] A. Bengtsson, A. Namutebi, M. L. Alimnger and U. Svanberg, "Effects of Various Traditional Processing Methods on the All-Trans-β-Carotene Content of Orange Fleshed Sweetpotato," *Journal of Food Composition and Analysis*, Vol. 21, No. 2, 2008, pp. 134-143. doi:10.1016/j.jfca.2007.09.006

[28] J. P. Mills, G. A. Tumuhimbise, K. M. Jamil, S. G. Thakkar, M. L. Failla and S. A. Tanumihardjo, "Sweet Potato b-Carotene Bioefficacy Is Enhanced by Dietary Fat and Not Reduced by Soluble Fiber in Mongolian Gerbils," *Journal of Nutrition*, Vol. 139, No. 1, 2009, pp. 44-50. doi:10.3945/jn.108.098947

[29] X. Ye, S. Al-Babili, A. Klöti, J. Zhang, P. Lucca, P. Beyer and I. Potrykus, "Engineering the Provitamin A (Beta-Carotene) Biosynthetic Pathway into (Carotenoid-Free) Rice Endosperm," *Science*, Vol. 287, No. 5451, 2000, pp. 303-305. doi:10.1126/science.287.5451.303

[30] J. A. Paine, C. A. Shipton, S. Chaggar, R. M. Howells, M. J. Kennedy, G. Vernon and R. Drake, "Improving the Nutritional Value of Golden Rice through Increased Pro-Vitamin A Content," *Nature Biotechnology*, Vol. 23, No. 4, 2005, pp. 482-487. doi:10.1038/nbt1082

[31] G. Tang, Y. Hu, S. A. Yin, G. E. Dallal, M. A. Grusak and R. M. Russel, "β-Carotene in Golden Rice Is as Good as β-Carotene in Oil at Providing Vitamin A to Children," *American Journal of Clinical Nutrition*, Vol. 96, No. 3, 2012, pp. 658-664. doi:10.3945/ajcn.111.030775

[32] G. Tang, J. Qin, G. Dolnikowski, G. R. Russell and M. A. Grusak, "Golden Rice Is an Effective Source of Vitamin A," *American Journal of Clinical Nutrition*, Vol. 89, No. 6, 2009, pp. 1776-1783. doi:10.3945/ajcn.2008.27119

[33] C. Pray, R. Paalberg and L. Unnevehr, "Patterns of Political Response to Biofortified Varieties of Crops Produced with Different Breeding Techniques and Agronomic Traits," *The Journal of Agrobiotechnology Management and Economics*, Vol. 10, No. 3, 2007, pp. 135-143.

[34] P. W. Heisey and W. Mwangi, "Fertilizer Use and Maize Production in Sub-Saharan Africa," *CIMMYT Economics Working Paper* 96-01, CIMMYT, Mexico D.F., 1996.

[35] E. T. Nuss and S. A. Tanumihardjo, "Quality Protein Maize for Africa: Closing the Protein Inadequacy Gap in Vulnerable Populations," *Advances in Nutrition*, Vol. 2, 2011, pp. 217-222.

[36] S. K. Kumar, "Adoption of Hybrid Maize in Zambia, Effects on Gender Roles, Food Consumption and Nutrition," IFPRI, Washington DC, 1991.

[37] T. Muzhingi, T. H. Gadaga, H. Siwela, M. A. Grusak, R. M. Russel and G. Tang, "Yellow Maize with High β-Carotene Is an Effective Source of Vitamin A in Healthy Zimbabwean Men," *American Journal of Clinical Nutrition*, Vol. 94, No. 2, 2011, pp. 510-519. doi:10.3945/ajcn.110.006486

[38] S. Li, A. Nugroho, T. Rocheford and W. S. White, "Vitamin A Equivalence of the β-Carotene in β-Carotene-Biofortified Maize Porridge Consumed by Women," *American Journal of Clinical Nutrition*, Vol. 92, No. 5, 2010, pp. 1105-1112. doi:10.3945/ajcn.2010.29802

[39] C. Davis, H. Jing, J. A. Howe, T. Rocheford and S. A. Tanumihardjo, "β-Cryptoxanthin from Supplements or Carotenoid-Enhanced Maize Maintains Liver Vitamin A in *Mongolian gerbils* (*Meriones unguiculatus*) Better than or Equal to b-Carotene Supplements," *British Journal of Nutrition*, Vol. 100, No. 4, 2008, pp. 786-793. doi:10.1017/S0007114508944123

[40] J. A. Howe and S. A. Tanumihardjo, "Carotenoid-Biofortified Maize Maintains Adequate Vitamin a Status in *Mongolian gerbils*," *Nutrition Journal*, Vol. 136, No. 10, 2006, pp. 2562-2567.

[41] M. L. Failla, C. Chitchumroonchokchai, D. Siritunga, F. F. De Moura, M. Fregene, M. J. Manary and R. T. Sayre, "Retention during Processing and Bioaccessibility of β-Carotene in High β-Carotene Transgenic Cassava Root," *Journal of Agriculture and Food Chemisty*, Vol. 60, No. 15, 2012, pp. 3861-3866. doi:10.1021/jf204958w

[42] J. A. Howe, B. Maziya-Dixon and S. A. Tanumihardjo, "Cassava with Enhanced Beta-Carotene Maintains Adequate Vitamin A Status in *Mongolian gerbils* (*Meriones unguiculatus*) Despite Substantial *cis*-Isomer Content," *The British Journal of Nutrition*, Vol. 102, No. 3, 2009, pp. 342-349. doi:10.1017/S0007114508184720

[43] L. Wenhong, "Vitamin A Equivalence of the β-Carotene in Biofortified Cassava in Women," *Graduate Theses and Dissertations*, Paper 10958, 2009.

[44] M. R. Lafrano, L. R .Woodhouse, D. J. Burnett, B. J. Burri, "Biofortified Cassava Increases β-Carotene and Vitamin A Concentrations in the TAG-Rich Plasma Layer of American Women," *British Journal of Nutrition*, First View Article, 2013, pp. 1-11.

