The basis for vitamin A deficiency in developing countries stem from low intake of bioavailable vitamin A foods. An integrated programme of supplementation, fortification and promoting consumption of local foods rich in vitamin A as well as supportive public health measures, represent key elements for prevention and control of vitamin A deficiency in many settings. A stepwise and combined approach of vitamin A capsule distribution and dietary diversification led to a successful control of vitamin A deficiency in Southern Thailand. A food-based strategy should be intensified when the population vitamin A profile reaches moderate to marginal levels of deficiency. In this context, implementation of a food-based programme can be used to indicate the progress of public health efforts to combat vitamin A deficiency.

In Asia and Africa where vitamin A deficiency is a public health concern, pro-vitamin A carotenoids contribute over 80 per cent of the food supply. Rural communities depend primarily on foods rich in provitamin A carotenoids such as dark green leafy vegetables, yellow and orange vegetables and fruits for their vitamin A supply. In recent years, several indigenous foods rich in beta-carotene, the highest activity of provitamin A carotenoids, have emerged as potential sources for promotion. Examples of these foods are buriti palm (18 mg beta-carotene/100g) from Brazil, drumstick leaves (15.4 mg beta-carotene/100g) and agathi leaves (19.7 mg beta-carotene/100g) from India, gac fruit (17-35 mg beta-carotene/100g) from Vietnam, ivy gourd (4.1mg beta-carotene/100g) from Thailand, etc. For many years, home and community gardening has been promoted to increase availability of nutrient rich foods for household consumption. In Bangladesh, Indonesia, the Philippines, Nepal and Thailand, the social marketing approach was successful in increasing consumption of vitamin A rich foods, including plant sources. Recently, the question was raised whether foods rich in provitamin A carotenoids can
contribute adequate vitamin A to the body.

**Efficacy of Provitamin A Carotenoids**

The bioavailability (fraction of the ingested amount that is absorbed) and bioconversion (fraction of the absorbed amount that is converted to retinol) of provitamin A carotenoids are influenced by a number of factors, for example, chemical structure, food matrix in which a carotenoid is incorporated, cooking methods, dietary fat, nutrient status (vitamin A, protein, zinc) of the host, genetic factors, and interactions among these factors\(^8\). In 16 studies conducted from 1958 to 1994, preschool children were fed dark green leafy vegetables, carrots or purified beta-carotene. Out of these, 13 studies reported an elevation of serum retinol from 3 to 24 mg/dl, while three others found no improvement\(^8\). However, these studies were consistent in demonstrating a higher serum response with the administration of purified beta-carotene or retinol supplements. The conflicting evidence led to a controversial issue since these studies had certain limitations in research design and methods. A later study in Indonesian lactating women\(^9\) failed to show improvement in serum and breast milk vitamin A to a daily diet of dark green leafy vegetables (3.5 mg beta-carotene per day for 12 weeks) while there was a positive effect to a similar amount of beta-carotene in enriched-wafers. The evidence posed a challenge to the efficacy of provitamin A foods in the prevention of vitamin A deficiency.

To address the controversy, a Coordinated Research Programme (CRP) on vitamin A nutrition\(^10\) was set up by the International Atomic Energy Agency (IAEA) with the use of the isotope dilution technique to assess the impact of dietary interventions in China, the Philippines and Thailand. The isotope dilution technique involving deuterated retinol has been developed to quantitatively estimate total body reserves of vitamin A in humans\(^11\). The study in China\(^12\) involved 46 children aged five to 6.5 years who received either green and yellow vegetables (0.7 mg beta-carotene/day) or light-coloured vegetables (0.7 mg beta-carotene/day) every weekday for 10 consecutive weeks. Serum retinol concentrations were sustained in the green and yellow vegetable group but they decreases significantly in the light-coloured vegetable group. Estimation of body stores using isotope dilution confirmed that children in the light-coloured vegetable group showed a decrease on average of 27 mmol or 7,700 mg retinol per child. On the other hand, the total body retinol stores of children in the green and yellow vegetable group were sustained.

The study indicated that carotenoid-rich vegetables were effective in maintaining adequate vitamin A nutrition and in protecting the children from becoming vitamin A deficient during the season when such food sources are scarce. In the Philippines\(^13\), school children (seven-13 year
(old) with marginal serum retinol concentrations (0.32-0.93 mmol/L) received lunch and snacks rich in provitamin A carotenoids on weekdays for 12 consecutive weeks. The foods provided on average, 13 mg beta-carotene per child per day. Following, intervention period, both serum retinol and beta-carotene concentrations significantly increased. The study also tested the ability of the three-day deuterated-retinol-dilution (DRD) procedure to detect changes in the pool size of body vitamin A. The three-day DRD showed an improvement in body vitamin A stores, especially among those whose status was low at baseline.

In summary, the study suggested that bioconversion of provitamin A carotenoids in plants to vitamin A in the body varies inversely with vitamin A status. In Thailand\textsuperscript{14}, 85 women with low serum retinol concentrations (<0.87 mmol/L) were randomised to receive a mid-day meal of either dark green leaves and yellow or orange vegetables and fruits (an average of 4.7 mg beta-carotene), purified beta-carotene in beverages (3.6 mg) or low-carotenoid foods (<0.5 mg beta-carotene) for 12 consecutive weeks. Following the intervention, serum retinol increased similarly in all groups, which is likely to reflect seasonal influences on habitual diet. On the other hand, breast milk retinol increased more in women receiving the provitamin A diet. Total body retinol stores tended to decline more in the control group. In summary, a short-term (three months) increase in dietary intake of beta-carotene rich foods had no effect on serum retinol and modestly increased breast milk retinol concentration but may have prevented a slight decline in total body retinol stores, that could result from breast feeding.

Based upon the evidence so far, the conventional provitamin-A foods are able to sustain body stores of vitamin A and, in certain conditions, may gradually contribute to hepatic reserves. The existing data also pose a challenge to the bioconversion factor of provitamin A carotenoids.

**Bioconversion Factor**

Bioconversion refers to the proportion of the absorbed provitamin A carotenoids which is converted to retinol. The 1967 FAO/WHO recommendation\textsuperscript{15} that 6 mg of beta-carotene has the same vitamin A activity as 1 mg of retinol has been challenged by emerging evidence. Recent studies\textsuperscript{16} of dietary interventions in Indonesia and Vietnam as well as studies involving the use of stable isotopes in China and Indonesia, reached similar suggestion that one retinol equivalent is derived from either 26-28 mg of beta-carotene in vegetables or 12 mg of beta-carotene in fruits. In 2000, the US Institute of Medicine\textsuperscript{17} (IOM) provided recommendations based on studies carried out in developing countries that 1 mg of retinol is equal to 2 mg of supplemental beta-carotene in oil or 12 mg of dietary beta-carotene or 24 mg of dietary alpha-carotene or beta-cryptoxanthin. The US IOM also introduced a
new term called Retinol Activity Equivalent (RAE) to express the vitamin A activity of provitamin A carotenoids which is half the activity of the former FAO/WHO Retinol Equivalent (RE).

The issue of bioconversion factor is challenged further through the development of isotopic tracer techniques\textsuperscript{18} to study bioavailability and bioefficacy of dietary carotenoids. The term “bioefficacy” refers to the efficiency with which dietary provitamin A carotenoids are absorbed and converted to retinol. By studying the plateau isotopic enrichment in 112 Indonesian school children, the amount of beta-carotene in oil that is required to form 1 mg of retinol is 2.6 mg\textsuperscript{16,19}. With the rapid advancement in technology development, more data need to be collected from both developed and developing countries in order to revisit the present recommendations on bioconversion of dietary carotenoids.

**Promising Provitamin A Food Sources for developing countries**

Based upon the IOM conversion factor, communities in developing countries that depend primarily on provitamin A carotenoids in their food supply, would roughly meet 60-70 per cent of the daily recommended intake\textsuperscript{16}. Therefore, enrichment of diet with richer sources of provitamin A carotenoids should be explored. In recent years, the use of carotene-pigment oil such as red palm oil (300-400 mg beta-carotene/g) has shown promising results. Crude red palm oil was used in India as early as the 1930s to treat vitamin A deficient children\textsuperscript{20}. During 1992 to 1994, a multicentre study was organised by the Nutrition Foundation of India\textsuperscript{5,20} to test the efficacy of red palm oil as the source of beta-carotene to counteract vitamin A deficiency. The addition of red palm oil to the feeding programmes at the Integrated Child Development Services Centres for six months resulted in a reduction in the clinical signs of vitamin A deficiency. In two other smaller scale studies, providing a daily dose of red palm oil (2,400 mg/day for two months) or larger dose (25,000 mg or 50,000 mg daily for 15 days) to Indian children produced similar efficacy in raising serum retinol concentration as large dose vitamin A supplements\textsuperscript{20}. A later study in the Honduras\textsuperscript{21} showed that addition of red palm oil to the maternal diet increased provitamin A carotenoids in breast milk and serum of the mother-infant pairs, the effect of which was similar to beta-carotene supplements. A recent study in Tanzania\textsuperscript{22} showed that provision of red palm oil to pregnant women led to significant increase in alpha- and beta-carotene concentrations in both breast milk and serum as well as maintenance of breast milk retinol concentration.

In Vietnam\textsuperscript{6}, the gac fruit (Momordica cochinchinensis Spreng) has been shown to contain high amounts of beta-carotene (17-35 mg beta-carotene/100g edible portion). Feeding rice mixed with gac fruit (3.5 mg beta-carotene/serving) to Vietnamese pre-schoolers for 30 days
resulted in a significant increase in plasma beta-carotene and retinol and appeared to improve haemoglobin concentrations in anaemic children\textsuperscript{23}. Current efforts have been made to produce gac fruit oil at the household or community level with the use of locally available materials\textsuperscript{24}. The oil contains a high concentration of beta-carotene (2,710 mg/ml) besides vitamin E and essential fatty acids. The average consumption is estimated at 2 ml/person/day. The production of gac fruit oil helps to increase beta-carotene intake and extend the use of oil beyond the available season of gac fruit. The promotion of gac fruit oil consumption holds the promise for improvement of vitamin A status in the Vietnamese population.

In addition to carotene-pigment oil, progress made in plant breeding technologies led to the introduction of new plant varieties with higher content of beta-carotene\textsuperscript{4} such as carrot, sweet potatoes, cassava, etc. These foods show strong potentials to raise the levels of intake and contribution to vitamin A status in the vulnerable population.

**Conclusion**

A review of the scientific evidence up to date indicates that conventional food sources of provitamin A carotenoids helps to maintain body stores and may gradually increase vitamin A in certain condition. The latest data suggested that bioavailability and bioconversion of dietary carotenoids are lower than expected. Based upon studies in developing countries, the US Institute of Medicine recommend the bioefficacy of beta-carotene in mixed diet as 1:12 and of other provitamin A carotenoids as 1:24. Additional evidence will be required for a wider application of the revised conversion factor of dietary carotenoids. In this context, a richer source of dietary provitamin A carotenoids is needed to meet the challenge of population-based vitamin A adequacy. Amidst this transition period, certain indigenous foods containing very high beta-carotene, such as red-palm oil, gac fruit and gac fruit oil as well as high beta-carotene plant varieties (carrot, sweet potato, cassava, etc) hold a future promise for the improvement of the vitamin A status of the vulnerable population.

*The author is a Senior Scientist at the Institute of Nutrition, Mahidol University, Thailand. The paper was presented at the IX Asian Congress of Nutrition.*

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