Review

Moving from Efficacy to Effectiveness: Red Palm Oil's Role in Preventing Vitamin A Deficiency

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Vitamin A deficiency is one of the most widespread nutritional deficiencies worldwide. Hundreds of millions of children and tens of millions of women living in Sub-Saharan Africa and Southeast Asia are at particularly high risk of the adverse health consequences associated with this largely preventable condition. Red palm oil comes from oil palms that are traditionally grown in tropical regions of West Africa and are now cultivated on a large-scale commercial basis in Southeast Asia. Red palm oil is the richest naturally occurring source of beta-carotene, a carotenoid that the human body can convert into usable vitamin A (retinol). This paper reviews a series of key intervention studies designed to investigate the impact of using red palm oil–based interventions to improve vitamin A status. These included studies from Africa, Asia, and Latin America in which red palm oil was used (or proposed for use) (1) as a dietary supplement, (2) as an in-home fortificant, (3) to fortify foods used for distribution in targeted supplementary feeding programs, and (4) to fortify staple food products. Overall, the results suggest that red palm oil is highly efficacious in improving vitamin A status among populations at risk of vitamin A deficiency. The time has come to move beyond trials of biological efficacy and focus on conducting operational research projects, effectiveness trials, and cost-benefit analyses that will help expand the use of red palm oil in areas where it is likely to be well accepted but remains underutilized as a dietary source of provitamin A.

Key teaching points:

- The global epidemiology of vitamin A deficiency (prevalence and location of population groups at risk) is briefly reviewed.
- The 3 most commonly used public health approaches for preventing vitamin A deficiency are summarized.
- The origin of red palm oil is discussed, along with the ways red palm oil could be used to increase the dietary intake of provitamin A carotenoids.
- Studies designed to investigate the biological efficacy of red palm oil in improving indicators of vitamin A status in humans or document the effectiveness of introducing and promoting red palm oil–based interventions into new communities are reviewed.
- Recommendations about future research needs are presented.

INTRODUCTION

Vitamin A is an essential nutrient that supports growth, development, immune function, and vision in humans. Vitamin A deficiency is largely unknown as a public health problem in many industrialized countries, but remains one of the major nutritional problems in developing countries where dietary sources of vitamin A are more limited. According to recent estimates from the World Health Organization, approximately 190 million preschool-age children (33%) and 19 million pregnant women (15%) living in countries at risk of vitamin A deficiency are biochemically deficient and at risk for the adverse health outcomes associated with this condition [1]. Countries in Africa and Southeast Asia have the highest proportion of children and pregnant women with vitamin A deficiency. The adverse effects of deficiency include, but are not limited to, an increased risk of morbidity and mortality and higher

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Abbreviations: MCH = maternal and child health, RAE = retinol activity equivalent, RDA = recommended dietary allowance.

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rates of anemia, xerophthalmia, and blindness, particularly among preschool-age children [2].

Vitamin A can be obtained from food, either as preformed vitamin A from animal products (such as dairy products, liver, and eggs) or as provitamin A carotenoids in certain plant products (particularly dark green leafy vegetables and dark yellow or orange fruits and vegetables such as sweet potatoes and mangoes). These include high concentrations of certain provitamin A carotenoids (primarily beta-carotene, but to a lesser extent, alpha-carotene and beta-crytoxanthin), which the body can absorb and then convert into retinol, the active form of vitamin A.

Various population-level strategies can be used to prevent vitamin A deficiency. While all countries use similar strategies, each country approaches the problem from a slightly different angle. Ideally, countries would identify a combination of interventions that would maximize the intake of vitamin A among different subpopulations at highest risk of deficiency (infants, preschool-age children, women of reproductive age, etc.) while decreasing conditions (such as parasitic infections) that may interfere with nutrient absorption and increase their individual needs for vitamin A.

Population-level interventions for improving vitamin A intake fall into 3 overlapping and complementary approaches: (1) fortification, (2) supplementation, and (3) dietary diversification strategies [3]. Food fortification generally involves the addition of preformed vitamin A to commonly consumed staple foods or condiments. This approach is used in countries with industrialized food production and marketing systems, but only benefits individuals who have access to and can afford to buy processed foods. Supplementation programs in which preschool-age children are routinely given high-dose vitamin A capsules (usually twice a year) have become a key component of child survival programs in many Asian and African countries where the majority of preschool-age children at risk of vitamin A deficiency live. Since the mid-1990s, dozens of major international donors and country governments have cooperated to distribute hundreds of millions of standardized doses of vitamin A. Many of these have been distributed during national-level campaigns and delivered in conjunction with childhood immunizations, deworming medication, and other health interventions [4].

The third major approach, dietary diversification, is also used in some developing countries and aims to increase the dietary intake of vitamin A through homestead food production, social marketing, and nutrition education activities. Dietary diversification programs may concentrate on improving vitamin A intake from animal foods, plant foods, or both. However, dietary diversification programs face several challenges. Since vitamin A–rich animal products are often relatively expensive, children in low-income families may not be able to eat them very often. In addition, although most plant foods are generally more affordable, many are available on a highly seasonal basis and some (particularly the green leafy vegetables) end up providing relatively low amounts of usable vitamin A because the carotenoids are poorly absorbed or metabolized for reasons related to the food matrix, amount of fat in the general diet (which is essential for absorption), and other host-related factors [5]. This situation presents a major challenge for policy makers and nutrition program managers interested in using food-based approaches to improving the vitamin A status of high-risk populations in developing countries.

Red palm oil is a unique plant food that naturally overcomes the problem of poor bioavailability. Red palm oil is the richest naturally occurring source of beta-carotene and generally contains a total of ~500–800 mg of provitamin A carotenoids/kg oil, which is ~15 times higher than the carotenoid content of carrots on a weight-by-weight basis [6]. Red palm oil is similar to olive oil in the sense that they are both produced from the fleshy part of a fruit, rather than from seeds (like canola or sunflower oil). In addition to being a very rich source of beta-carotene, the carotenoids in red palm oil are easily absorbed because they are already dissolved in oil.

Red palm oil has traditionally been an important cooking oil in the diets of populations living in or near the tropical rain forest regions of West Africa where the oil palms originated [7]. Many of these countries (including Burkina Faso, Cameroon, Ghana, Ivory Coast, Nigeria, etc.) produce red palm oil for local consumption and some have developed commercial industries for exporting other palm oil–based products. Red palm oil is consumed much less frequently in other parts of Africa, but certain areas, including parts of Tanzania and Kenya, have small climatic zones suitable for growing the oil palms.

At various times over the past 500 years, oil palms from West Africa were exported to other tropical countries in Latin America and Southeast Asia by the Portuguese, Dutch, and British. In Brazil, red palm oil is consumed in parts of the northeast where oil palms were imported during the slave trade. Several other Latin American countries have developed a commercial oil palm industry over the past 50 years and now produce palm oil–based products for the export market. In Southeast Asia, the oil palm industry began over 100 years ago. Malaysia and Indonesia are by far the largest globally commercial producers of palm oil. During the refining process most of the carotenoids are removed from the crude palm oil to produce a variety of raw materials for use in many industrial and food technology applications. However, the carotenoid-rich type of red palm oil is only consumed on a limited basis as the part of traditional diets outside of Africa and northeast Brazil.

PURPOSE OF THE REVIEW

We were asked to provide a critical review of the human studies that have been published about red palm oil's efficacy in fighting vitamin A deficiency and to comment on the larger issue of how red palm oil fits into global efforts to address this problem.

CONCEPTUAL FRAMEWORK AND METHODOLOGY

A wide range of published studies that either used or proposed how red palm oil–based interventions could influence the vitamin A status of a variety of populations was reviewed. Because red palm oil can be stored and transported over long distances without necessarily losing its provitamin A activity, publications that proposed ways to use red palm oil are also cited, even if they were not tested in an intervention trial, because these illustrate the ways red palm oil was considered for use in the past or how it might be used in the future.

Studies that examined the efficacy and/or effectiveness of red palm oil–based interventions in preventing and treating vitamin A deficiency were considered, as well as studies that focused on key factors that might affect these outcomes. Both efficacy and effectiveness are relevant when considering the role that red palm oil might play in preventing vitamin A deficiency. Red palm oil–based interventions that are biologically capable of changing the vitamin A status of individuals under well-controlled conditions (efficacious) may be more or less effective in reducing the severity or prevalence of vitamin A deficiency when scaled up and implemented as a population-level program.

Vitamin A deficiency can be assessed using various biochemical and clinical indicators of vitamin A status [8]. Serum retinol concentrations are now the most widely used biochemical indicator in population-based surveys and intervention trials, even though serum retinol concentrations are homeostatically controlled and may not decline until an individual's body stores are quite low. However, serum retinol is a useful indicator for measuring population-level changes in the prevalence of vitamin A deficiency. Low serum retinol is defined as concentrations <0.70 µmol/L in preschool-age children (6–71 months old) [8]. In adults, serum or breast milk retinol concentrations <1.05 µmol/L are considered indicative of low vitamin A status.

Total body stores of vitamin A can be measured using isotope dilution techniques, while liver stores of vitamin A can be estimated using indirect testing methods such as the modified relative dose response test. However, these techniques are expensive and require highly skilled laboratory technicians and facilities. Although occasionally used in intervention trials, these indicators have been most often used in studies focused on measuring the bioavailability of different types and combinations of carotenoids.

Several clinical indicators of vitamin A status also exist (night blindness, Bitot's spots, etc.). Although useful for identifying individuals with severe vitamin A deficiency, they are less effective in detecting a population-level response to interventions in settings where most individuals suffer from milder forms of deficiency. Clinical indicators were more commonly used in population-based prevalence surveys and intervention trials among children before the techniques for measuring serum retinol concentrations became widely available. However, the prevalence of night blindness (which can be easily ascertained by field workers trained to ask a standard set of questions) is still used as an indicator of vitamin A status in more comprehensive nutrition and health surveys conducted in developing countries.

In order to identify relevant studies for this review, an initial search was conducted using the U.S. National Library of Medicine's PubMed website (http://www.ncbi.nlm.nih.gov/PubMed) using the key words ''red palm oil'' and ''palm oil'' with no language restrictions. The titles and abstracts of the articles identified were reviewed and full copies of the most relevant articles were obtained. Studies that included any indicators of vitamin A status were reviewed as well as studies that measured serum or breast milk carotenoid profiles as the primary outcome. Additional articles were identified in several different ways: from the list of citations in relevant publications, by searching the table of contents of journals that contained relevant articles but were not indexed in PubMed, and from Internet-based searches other than PubMed, using the key words ''red palm oil'' and ''palm oil.''

RESULTS

Publications that mentioned red palm oil and vitamin A or vitamin A–related health outcomes were identified for specific countries in Asia (China, India, Indonesia, and Papua New Guinea), Africa (Burkina Faso, Nigeria, South Africa, Tanzania, and Zambia), Latin America (Brazil, Guatemala, and Honduras), as well as Europe (Spain). These represent countries where red palm oil has been produced for many years and is a well-known part of traditional diets, countries where oil palms were a newly introduced crop and red palm oil was an unfamiliar food item, and some countries (or areas of countries) where the oil palms cannot grow and where red palm oil will remain an imported food product.

The reviewed studies were published over the 80-year time span leading up to 2010. The studies were based on red palm oil grown in multiple countries and processed in several different ways. Some studies used crude or partially refined red

Table 1. Amount of Red Palm Oil Needed to Supply the U.S. Recommended Dietary Allowance (RDA) of Vitamin A Each Day [9]

Subpopulation (Years Old)	RDA	Conversion Factor			
		6:1[1]		12:1[2]	
	Retinol Activity Equivalents (μg)	Beta-Carotene (μg)	Red Palm Oil (g)[3]	Beta-Carotene (μg)	Red Palm Oil (g)[3]
1–3	300	1800	3.6	3600	7.2
4–8	400	2400	4.8	4800	9.6
9–13	600	3600	7.2	7200	14.4
Females (14+)	700	4200	8.4	8400	16.8
Pregnant women (14–18)	750	4500	9.0	9000	18.0
Pregnant women (19+)	770	4620	9.2	9240	18.5
Males (14+)	900	5400	10.8	10,800	21.6
Lactating women (14–18)	1200	7200	14.4	14,400	28.8
Lactating women (19+)	1300	7800	15.6	15,600	31.2

[1] Assumes a beta-carotene concentration of 500 ppm (500 μg beta-carotene/g red palm oil) and that 6 μg beta-carotene in red palm oil provides 1 μg retinol activity equivalent.

[2] Assumes a beta-carotene concentration of 500 ppm (500 μg beta-carotene/g red palm oil) and that 12 μg beta-carotene in red palm oil provides 1 μg retinol activity equivalent.

[3] Although the density of red palm oil is slightly less than 1.0, 1 mL of red palm oil weighs ~1 g. Using this assumption, the amount of oil (in teaspoons) is estimated as the amount of oil in g/5 mL, while the amount of oil (in tablespoons) is estimated as the amount of oil in g/15 mL.

palm oil processed using more traditional methods, while others used highly refined red palm products produced on a commercial basis. This means that the chemical composition, the carotenoid profile, the total carotenoid content (and thus, the total vitamin A activity) of the red palm oil–based interventions differed over time and across studies. Although most of the intervention studies reported the amount of red palm oil the intervention intended to deliver, only some reported the estimated carotenoid content or the total vitamin A activity measured in terms of retinol activity equivalents (RAEs).

The following assumptions were used in order to provide a general estimate of the vitamin A activity delivered by various interventions. First, a total carotenoid content of 500 mg/kg of red palm oil was assumed. Although red palm oil contains a mixture of carotenoids with provitamin A activity (beta-carotene and alpha-carotene, with very minor amounts of other carotenoids), beta-carotene is more abundant and better converted than alpha-carotene. Second, the RAE of red palm oil was calculated using the 12:1 conversion factor proposed in 2001 by the U.S. Institute of Medicine for beta-carotene consumed as part of a mixed meal [9] as well as the previously recommended conversion factor of 6:1 for beta-carotene in oil [10]. Although other studies suggest that the bioavailability of beta-carotene in oil or red palm oil may be even higher [11,12], most of the intervention studies incorporated red palm oil into a processed, baked, or cooked food product that was eaten as part of a meal rather than as delivering it as a stand-alone supplement.

Table 1 shows the amount of red palm oil that would need to be consumed on a daily basis to meet dietary intakes ranging from 300 μg to 1300 μg RAEs. The lower end represents the U.S. Recommended Dietary Allowance (RDA) for 1- to 3-year-old children (~1–2 teaspoons/d), while the higher end reflects the RDA for lactating women (~1–2 tablespoons/d) [9]. This table illustrates that it would be feasible to meet daily nutritional needs for vitamin A by consuming red palm oil, even if the more conservative assumption about the appropriate conversion factor effectively doubles the amount required.

The Structure and Function of Beta-Carotene and Red Palm Oil as a Treatment for Xerophthalmia

The earliest publications are from the time period when the chemical structure, biological function, and dietary sources of vitamin A and beta-carotene were initially being recognized. These include a 1929 laboratory study conducted by British researchers that identified beta-carotene as a biologically active component of red palm oil [13] and a 1937 hospital-based study from India in which an emulsion containing red palm oil obtained from Malaya (current-day Malaysia) was found to be equally effective as cod liver oil (the standard of care) in treating children with the characteristic eye lesions associated with severe vitamin A deficiency [14].

Observational Studies and Anecdotal Reports

These studies were followed by observational studies and anecdotal reports published from the late 1950s to the early 1970s by clinicians working on the epidemiology of blindness in Africa who noted a possible link between higher consumption of red palm oil, improved vitamin A status, and apparently lower rates of blindness [15–17]. A more recent observational study from Nigeria in 2002 found weak evidence of a protective relationship between red palm oil consumption and less severe malaria in the subgroup of children >36 months old [18].

Intervention Trials with Indicators of Vitamin A Status and Health Outcomes

Red palm oil can be used as an intervention for improving vitamin A status in several different ways. At the household level, red palm oil can be used as a dietary supplement for individuals or as an in-home fortificant when it is added to food items prepared for specific individuals (for example, weaning foods for young children) or for the entire family. In institutional settings, red palm oil can be used to fortify food items produced for distribution in targeted supplementary feeding programs. In addition, at the commercial level, red palm oil can be used to fortify staple food items or condiments. Table 2 summarizes the results of the key intervention trials reviewed in this article. The studies are listed according to type of intervention and then chronologically in order of publication date. Each study site is listed individually, but multiple studies or related publications may be grouped. Some of the smaller pilot studies are discussed in the text but are not presented in the table.

Several other potential applications for red palm oil were mentioned in the literature. These include using red palm oil as a replacement for the peanut oil and synthetic vitamin A used to fortify sugar in Central America [19], adding red palm oil to cooking oils in Brazil [20], using red palm oil to produce a high-energy, micronutrient-dense, fat-based spread for treating children in clinical and emergency settings [21], adding red palm oil to chunky tomato-based condiment sauces in Guatemala [22], and promoting the use of Carotino (a commercially available red palm oil product from Malaysia) as a salad dressing [23] and a fortificant in a variety of commercial baked goods [24]. These applications are not discussed here in more detail because articles that tested their efficacy in improving the vitamin A status of populations at risk of deficiency were not found in the biomedical literature. Studies from China [25] and Spain [26] were excluded because they were conducted in healthy adults and focused on changes in carotenoid profiles, rather than on indicators of vitamin A status.

Red Palm Oil Used as a Dietary Supplement

The earliest community-based intervention trial of red palm oil, vitamin A status, and child health took place in Indonesia in the mid-1960s as the commercial production of oil palms began to expand in Southeast Asia [27]. The Indonesian studies assessed the acceptability of red palm oil–based interventions in a population where red palm oil was not a part of the traditional diet and measured the effects on child growth and biochemical and clinical indicators of vitamin A status.

In an initial pilot study, a group of ~50 boys (half of whom exhibited clinical eye signs of vitamin A deficiency) were supplemented with a daily dose (per kg of body weight) of either 1 g red palm oil, 1 g coconut oil, 2 g skim milk powder, 2 g sugar, or a 2,000-IU dose of synthetic vitamin A (vitamin A acetate) over a 3-week period. The effect of these supplements on biochemical indicators of status (circulating levels of serum retinol and carotene) as well as clinical symptoms of vitamin A deficiency were measured. Serum carotene levels rose dramatically among those who received red palm oil, while serum retinol levels rose and remained elevated among those who received either red palm oil or synthetic vitamin A. Night blindness disappeared among the boys who received either red palm oil or vitamin A acetate [27].

In a much larger community-based trial involving ~650 children, those living in villages who were assigned to receive a daily dose of 4 mL red palm oil (~3000 units of provitamin A) or a daily dose of ~2400 IU of synthetic vitamin A (in a vitamin A and D–fortified skim milk powder) had higher serum retinol concentrations compared to those assigned to receive decolorized red palm oil or no intervention after ~1 year [28,29]. On the other hand, the interventions had an equivocal impact on clinical eye signs of deficiency. Parents had been instructed to give the oil as a ''vitamin medicine'' rather than mixing it in with the children's food and compliance was not monitored. Some parents reported that the children did not like the supplement and a certain percentage of children probably received far less than the prescribed amount.

The other intervention study that tested the impact of red palm oil delivered as a short-term dietary supplement was conducted in the late 1990s and involved ~90 lactating women in Honduras [30,31]. Women consumed a total of 90 mg beta-carotene in red palm oil, 90 mg synthetic beta-carotene, or placebo every other day (15 mg/d for 6 days) over a 10-day period. Although tested as a short-term dietary supplement, the red palm oil was stirred into a serving of black beans and served as part of a breakfast meal. Short-term supplementation with red palm oil improved serum and breast milk carotenoid (but not retinol) concentrations in the women. Infant serum retinol concentrations increased slightly, and no effect was detected on liver stores of vitamin A in either the mothers or their infants. At the time, oil palms were grown for commercial export in the northern part of Honduras, but red palm oil was not marketed as a local food product.

Red Palm Oil Used as an In-Home Fortificant

The earliest intervention trial of red palm oil as an in-home fortificant was conducted in Papua New Guinea in the early 1980s after the commercial production of oil palms began expanding there. Red palm oil was initially tested in a 9-month

Table 2. Key Studies Involving Red Palm Oil–Based Interventions Conducted among Populations at Risk of Vitamin A Deficiency

Country, Author, Year	Type of Red Palm Oil–Based Intervention	Source of Red Palm Oil	Results among Red Palm Oil Recipients
Daily supplementation			
Indonesia, Lian, 1967 [28], 1968 [29]	Daily supplement of red palm oil (>1-yr study); the parents were advised to directly administer a specified amount of oil to each preschool-age child vs. negative control (no intervention) vs. positive control (decolorized red palm oil)	Indonesia	Serum retinol concentrations improved in preschool-age children; equivocal impact on clinical signs of deficiency
Honduras, Canfield, 2000 [30], 2001 [31]	Short-term supplementation (6 times in 10 days) of red palm oil mixed with breakfast meal to hide color vs. negative control (placebo capsule) vs. positive control (capsule containing synthetic beta-carotene)	Malaysia	Carotenoids increased in breast milk and maternal serum; infant serum retinol increased slightly; no impact on liver stores of vitamin A
In-home fortificant			
Papua New Guinea, Binns, 1984 [32], Pust, 1985 [33]	In-home fortificant; the parents were advised to mix a specified amount of red palm oil into each child's serving of mashed sweet potatoes vs. negative control (no intervention) in the 9-mo pilot study; the larger 12-mo trial used a 2 × 2 factorial design and included monthly deworming treatment for children	Papua New Guinea	Improved growth among preschool-age children in the pilot study, but not at the end of the larger trial; no serum retinol results reported, due to technical problems
Tanzania, Lietz, 2000 [34], 2001 [35], 2006 [36]	In-home fortificant; pregnant women were provided with red palm oil + dietary advice about consuming dark-green leafy vegetables vs. sunflower oil + dietary advice (positive control) vs. dietary advice only (negative control). Women were advised to add a specified amount of oil to the meals they cooked for the entire household; 6-mo intervention study through 3 mo postpartum	Malaysia (Carotino oil)	Carotenoid (but not retinol) concentrations increased in serum and breast milk; red palm oil maintained but did not increase milk retinol concentrations in early lactation
India, Radhika, 2003 [37]	In-home fortificant; pregnant women were given sachets of red palm oil vs. groundnut oil (negative control) and instructed to consume it on a daily basis mixed with food; 8-wk intervention period.	Malaysia (Carotino oil)	Serum retinol concentrations improved in women; higher retinol concentrations in cord blood samples of infants
Burkina Faso, Zagre, 2002 [39], Zagre, 2003 [40]	In-home fortificant; red palm oil made available in local markets and promoted through large-scale social marketing activities; mothers were advised to add red palm oil to food at the end of the cooking process; amount based on the total number of servings prepared for the household (no control group); 30-mo study	Burkina Faso	Serum retinol concentrations improved among preschool-age children and women of reproductive age
Fortified food distributed through targeted supplementary feeding program			
India, multiple studies from 1991 to 2002 [41–52]	Multiple feasibility studies and feeding trials among preschool- or school-age children, some with positive controls (synthetic retinol) or negative controls (groundnut oil)	India	Indicators of vitamin A status generally improved among preschool- and school-age children
South Africa, van Stuijvenberg, 2000 [53,54], 2001 [55]	Red palm oil–fortified biscuits distributed to school children on a daily basis vs. positive control (biscuits fortified with synthetic beta-carotene) vs. negative control (unfortified biscuits); 6-mo study and 3-mo study	Malaysia	Initial study found no differences in serum retinol concentrations among school children, but the second found equal improvements in the red palm oil and beta-carotene groups
Burkina Faso, Zeba, 2006 [56]	School lunch program Site 1: red palm oil added to individual children's meals 3 ×/wk over ~9 wk in 1 school year Site 2: red palm oil added to individual children's meals 3 ×/wk vs. negative control (no intervention) vs. positive control (one 60-mg dose of retinol) over ~17 wk in 1 school year	Burkina Faso	Serum retinol concentrations improved among school children between baseline and 12 mo later
Fortified staple food (produced by small-scale or commercial producers)			
Tanzania, Mosha, 1999 [57]	Small-scale local producers trained to add red palm oil during the production of dried cassava flour (staple food product); community members in pilot village encouraged to use fortified cassava flour vs. negative control (continued use of unfortified flour in control villages); 20-mo intervention period	Tanzania	Serum retinol concentrations improved among preschool-age children and pregnant and lactating women

pilot study involving ~180 children and was used more as a way to increase the energy content of children's diets and growth than as an intervention for preventing vitamin A deficiency, *per se* [32]. Red palm oil (800 g per child/mo) was distributed to families through monthly maternal and child health (MCH) clinics and the families were instructed to give the children a prescribed amount of red palm oil every day (~28 mg) mixed in with mashed sweet potatoes, the staple food item. The net consumption was estimated as 80% overall, but a small percentage of children (~6%) disliked the product and ate very little. Child growth improved among those receiving red palm oil, but indicators of vitamin A status were not measured.

The 12-month follow-up study assigned local MCH clinics to distribute 1 of 4 intervention packages to a total of ~900 preschool-age children: (1) red palm oil (800 g per child/mo), (2) monthly deworming (pyrantel) during clinic visits, (3) red palm oil (800 g per child/mo) and monthly deworming (pyrantel) during clinic visits, or (4) no interventions to their regular attendees [33]. Children receiving red palm oil had better growth during the first 3 months of follow-up, but no differences were observed at the end of 12 months. Although blood samples had been collected to measure indicators of vitamin A status in a subset of children, the samples were damaged in transit to the laboratory in Australia and could not be analyzed. One particularly interesting observation is the description of how fats and oils are highly valued in traditional Highland culture (as a body adornment for certain rituals as well as being a rare and favored food). The authors speculate that a series of unusual cultural and political events may have caused a greater demand for oils overall and that some of the red palm oil may have been used by other family members rather than being fed to the children as intended. This highlights the need to carefully position and promote red palm oil–based interventions so that the oil will reach the intended targets with as little sharing or wastage as possible.

Tanzania was the site of a more recent study in the late 1990s that measured the impact of red palm oil consumed as an in-home fortificant on the vitamin A status of lactating women [34–36]. A total of 90 pregnant women were recruited during the last trimester of pregnancy and followed until 3 months postpartum. A control group of women was provided dietary advice and encouraged to maintain their consumption of dark-green leafy vegetables. The second and third groups were given the same dietary advice plus a monthly supply of either sunflower or red palm oil. Women in the oil groups were given cooking demonstrations and suggestions about incorporating the oil into local recipes. They were advised to add a prorated amount of oil (with ~12 mL for themselves), to add the oil at the end of the cooking process, and to not heat it too much. The red palm oil intervention was designed to provide a total of ~200,000 IU retinol over the 6-month period. Consumption of red palm oil increased the carotenoid concentration of women's plasma and breast milk at 3 months postpartum, but did not result in higher plasma or breast milk retinol concentrations. On the other hand, breast milk retinol concentrations decreased between 1 and 3 months postpartum among women in the control group, but remained stable among women in both the red palm oil and sunflower oil groups.

In India, another study conducted in the late 1990s investigated the impact that red palm oil consumption had on the vitamin A status of ~130 pregnant women and their newborn infants [37]. Women recruited at 16–24 weeks of gestation were randomized to begin supplementation during their third trimester of pregnancy. Women were supplied with sachets containing either 8 mL red palm oil (Carotino oil from Malaysia) or 8 mL groundnut oil and were instructed to consume the oil with their regular meals on a daily basis over an 8-week period between 26–28 and 34–36 weeks of gestation. The red palm oil intervention was designed to provide a daily dose of 2400 μg beta-carotene (slightly less than the RDA of vitamin A) for pregnant women in India. Maternal serum retinol concentrations were measured at enrollment and again at the beginning and end of the 8-week intervention period. Serum retinol concentrations declined to an equal extent between enrollment and the start of the intervention in both groups of women, but after 8 weeks had improved among women who consumed the red palm oil compared to those in the groundnut oil group. The infants of women in the red palm oil group also had higher retinol concentrations in their cord blood samples at birth.

In Burkina Faso, the feasibility [38] and effectiveness [39,40] of introducing red palm oil as an in-home fortificant were examined over a 30-month study conducted during the late 1990s. The study area was in a part of the country where red palm oil was not usually available or consumed and included a target group of ~10,000 women and preschool-age children. Red palm oil from the southern part of the country was retailed locally and widely promoted using a combination of social marketing activities. The oil was intended for use as a ''supplement'' (suggested ''dose'' of 10 mL) that would be added to mothers' and children's plates of food right before serving, rather than as a cooking ingredient or seasoning oil for the entire family. The 24-month follow-up survey found that red palm oil was well accepted in the community and that ~50% of the mothers and children reported consuming it during the previous week. Serum retinol concentrations were measured in ~200 mothers and children at baseline and in ~140 at the end of the intervention period. Serum retinol concentrations improved in mothers and children when compared to baseline assessments. However, the prevalence of low serum retinol concentrations (<0.70 μmol/L) during the 24-month follow-up survey was still quite high (67% in preschool age children; 28% in women), which suggests that additional efforts are needed to prevent vitamin A deficiency in that setting.

Red Palm Oil Used to Fortify Food Products or Meals Distributed through Targeted Supplementary Feeding Programs

Three sets of studies investigated the use of red palm oil as an ingredient for fortifying food products intended for distribution through targeted supplementary feeding programs for children. In the first setting (India), the feasibility of adding red palm oil to various food items was explored for distribution to preschool-age children attending day care centers. In the second setting (South Africa), red palm oil was used to fortify biscuits distributed as a snack food to primary school children. In the third setting (Burkina Faso), red palm oil was added to the primary school children's meals as part of a school lunch program.

A series of studies was conducted during the late 1980s and 1990s in India to examine the safety, stability, and acceptability of food products prepared with red palm oil as part of a larger initiative to help meet India's rising demand for edible oils by expanding the local production of red palm oil in the southern part of the country. The results of these studies have been comprehensively reported and reviewed in multiple publications and are not discussed in detail here [41–52]. Briefly, several studies explored the feasibility of using red palm oil to fortify food products for preschool-age children attending day care centers in the national Integrated Supplementary Child Development Services Programme. Others were conducted on primary school children or focused on comparing the impact of various doses of red palm oil to various doses of retinol on clinical indicators of vitamin A status, serum retinol concentrations, or liver stores of vitamin A. The key findings were that sweet snack foods were relatively well accepted by children. Most studies found that the daily consumption of foods containing red palm oil was efficacious in improving indicators of vitamin A status. The review article by Rao [49] provides an overview of the research on red palm oil and health in India conducted prior to 2000, along with some of the key challenges that were encountered, including the problem of identifying food products that children would accept.

In South Africa, 2 studies conducted in the late 1990s investigated the impact that beta-carotene–fortified biscuits distributed as part of a school feeding program had on the vitamin A status of ~270 school-age children. The first study compared the effect of placebo biscuits to the effect of biscuits fortified with red palm oil or synthetic beta-carotene (both providing 34% of the children's RDA) [53]. Biscuits were distributed on a daily basis, 5 times per week, for ~6 months. Serum retinol concentrations were measured at the beginning and end of the study and improved to a similar extent in all 3 groups. The authors identified 2 events that interfered with execution of the study. First, a new school lunch program was introduced into the area during the last 4 weeks of the study period and provided all children with an additional 33% of their RDA of vitamin A. Second, the beta-carotene content of the red palm oil–fortified biscuits distributed during the last 8 weeks of the study provided only half of the intended amount of provitamin A because the red palm oil had been improperly stored and much of the carotenoid content had degraded before the last batch of biscuits was produced. This highlights the need for maintaining good quality control procedures when producing any fortified food product. However, the study did demonstrate that the fortified biscuits were well accepted among the school children.

A second follow-up study was conducted in a new area where no school lunch program confounded the results of the trial [54,55]. This study used a similar design, but fortified biscuits at a slightly lower level (30% of the RDA) and had a shorter intervention period (3 months). The fortified biscuits were also well accepted by this new group of ~400 school children. The magnitude of the improvement in serum retinol concentrations between baseline and follow-up was smaller than in the previous study, but serum retinol concentrations improved to the same extent among children who received either red palm oil or synthetic beta-carotene–fortified biscuits as compared to children who received placebo biscuits.

In Burkina Faso, the impact of adding red palm oil to school children's meals was tested in 2 sites over a 12-month period [56]. Neither of these sites was located in the traditional red palm oil–producing area of the country. In the first site, ~15 mL (1500 μg RAEs) of red palm oil was added to individual school children's meals 3 times a week for ~9 weeks for a total of ~42 mg RAEs over the entire period (based on a 6:1 conversion factor). Changes in serum retinol concentrations were measured at baseline and again 12 months later in the same group of ~215 children, with increases noted among the children who received red palm oil with their meals. In the second site, 3 sets of schools (~340 children) participated in a different study. In one group of schools, red palm oil was added to the children's meals 3 times a week for ~17 weeks (for a total of ~76.5 mg RAEs), the second group of children ate normal school lunches and were given 1 high-dose vitamin A capsule (60 mg RAEs) in mid-June 2004 at the end of the school year (midway between the serum retinol surveys), and the third group of control children simply ate normal school lunches. Changes in serum retinol concentrations were measured at baseline and again 12 months later (6 months after the red palm oil intervention had ended). Similar improvements were observed among children who consumed red palm oil along with their meals or a single vitamin A capsule. However, ~15% of children still had low serum retinol concentrations, which suggests that additional interventions (either longer-term and/or a higher effective dose) would have been needed to achieve or maintain a lower prevalence of vitamin A deficiency.

Red Palm Oil Used to Fortify Staple Food Products

One study from the mid-1990s investigated how red palm oil could be used to fortify cassava flour, a widely consumed staple food item in certain parts of Tanzania [57]. This 20-month study was conducted in an area of the country where oil palms grew, but where red palm oil was underutilized as a food source of provitamin A. A series of community-level demonstrations and workshops was held in 3 pilot villages where women were trained how to incorporate red palm oil into the cassava flour production process. The intervention was designed to produce flour that would deliver slightly more than the daily required amount of vitamin A for preschool-age children based on their normal intake of foods prepared with unfortified cassava flour. Social marketing techniques were used to promote the production and use of the fortified flour for preparing weaning foods and family meals. Two other villages served as control areas and continued to produce and use cassava flour as usual. The results of the feasibility study showed that the new production process was well accepted and that most women used the flour to produce weaning foods. Preschool-age children in the intervention villages had higher serum retinol concentrations and improved growth compared to those in the control villages. Serum retinol concentrations also improved among lactating and pregnant women in the intervention villages.

Limitations of the Review

This review focused primarily on articles published in the biomedical literature that were indexed and published (at least in abstract form) in English. Studies published in the ''grey'' literature and in languages other than English may not have been included.

Quality of the Intervention Studies

In general, the more recent intervention studies used stronger study designs and larger sample sizes and measured and reported more details about the results and factors that may have influenced them. Some studies used a pre-post test design and measured changes in serum retinol concentrations among the same individuals, while others used negative and/or positive control groups. Both of these designs support strong inferences about the efficacy of red palm oil–based interventions. Since serum retinol concentrations are homeostatically controlled, the fact that most studies observed a positive response in this indicator suggests that red palm oil was highly efficacious in improving vitamin A status in various population groups.

Information Gaps

Some, but not all, studies explicitly reported the assumptions used to estimate the vitamin A activity provided by the red palm oil–based interventions. Future studies should include these details. At a minimum, the initial carotenoid content of the red palm oil, the amount of oil delivered, and the conversion factor(s) used to calculate RAEs should be reported. Studies that compare dietary intakes to RDA should also clearly state the source of the dietary recommendations. This would make it easier to understand what was done and how to compare the findings across studies.

Many of the articles stated that red palm oil is an inexpensive and widely available commodity, but relatively few provided details about the actual costs involved in producing, processing, transporting, or promoting red palm oil or food products fortified with red palm oil to the study participants. Future studies should include this type of information so the cost of developing and delivering red palm oil–based interventions can be estimated and compared to other population-based strategies for preventing vitamin A deficiency.

Global Trends in Nutrition Programming over the Past 10 Years

Several studies regarding the bioavailability and efficacy of red palm oil were published around 10 years ago, at a time when interest in developing sustainable food-based approaches for preventing vitamin A deficiency was high but basic questions about the vitamin A activity of carotenoids in different plant foods remained. The new bioconversion factor of 12:1 proposed by the U.S. Institute of Medicine in 2001 for the RAE of beta-carotene effectively halved the global dietary supply of vitamin A available from plant-based foods. This prompted new thinking about the appropriate mix of interventions that might be needed to more effectively prevent vitamin A deficiency in certain settings [11]. However, this change should not diminish enthusiasm for red palm oil–based interventions because consuming even relatively small amounts of red palm oil will go a long way toward meeting daily requirements for vitamin A.

At the same time, more emphasis has been placed on preventing the adverse health risks associated with other highly prevalent micronutrient deficiencies (for example, iron, zinc, and iodine) and developing interventions capable of simultaneously addressing multiple micronutrient deficiencies [58,59]. International research initiatives have been launched to develop biofortified staple food crops containing higher concentrations of beta-carotene, iron, and/or zinc. These include new high beta-carotene varieties of cassava, maize, and sweet potatoes for Africa [60] and golden rice for use in Asia [61]. New fortified food products are being produced and used to prevent and treat multiple micronutrient deficiencies among preschool-age children. These include Sprinkles, a micronutrient powder sold in single-serving size sachets and used as an in-home fortificant [62], and Plumpy'Nut, a ready-to-use therapeutic food used in the community management of acute malnutrition [63]. The coverage of periodic vitamin A supplementation programs for preschool-age children has expanded rapidly over the past 10 years [4,64] and ongoing efforts continue to support a wide variety of public-private partnerships and national food fortification programs [65,66]. These are all promising developments in the global efforts to prevent vitamin A deficiency.

Barriers to Expanding the Use of Red Palm Oil–Based Interventions

The potential barriers in expanding the use of red palm oil–based interventions globally are likely to be country-specific and will depend on multiple factors. Among others, these include local dietary habits and food preferences, the local availability and cost of red palm oil, and the existing policies, programs, preferences, and resources available to fund interventions for preventing vitamin A deficiency.

Consumer acceptance is clearly a key factor in the success of any intervention involving red palm oil. Red palm oil has a very strong and distinctive color, odor, and taste that is familiar and well-liked in many parts of West Africa. Thus, objections to the color and taste are less likely to be a barrier in expanding its use among populations in Africa who live outside the specific areas where oil palms are grown. The studies from Burkina Faso clearly demonstrate that it was possible to successfully introduce red palm oil to communities in the northern and eastern regions of that country. However, some of the early studies conducted in Asia where red palm oil was a completely unfamiliar food item identified the color, taste, and odor as potentially important barriers for ongoing use among preschool-age children.

There are several ways to help overcome this problem. These include processing red palm oil in a way that reduces the strong taste and odor and/or developing fortified food products that will partially mask these qualities. Carotino is a commercial product that was specifically developed to retain most of the provitamin A carotenoids while eliminating some of the stronger flavors and odors associated with red palm oil processed using more traditional methods. This product is currently produced in Malaysia and was specifically mentioned as the starting material used in several of the intervention studies published around 2000. In one sense, a highly processed red palm oil product (like Carotino) functions more like a simple replacement for synthetic beta-carotene in fortified food products and less like a sustainable food-based intervention. Several reviewers have considered how a product like Carotino could help address vitamin A deficiency among at-risk populations [22–24]. However, in order to be effective, fortified foods produced using Carotino would need to be acceptable, accessible, and affordable to the populations most at risk.

Expanding the use of red palm oil as an in-home fortificant to communities outside the traditional red palm oil–producing areas in Africa may be hampered by the availability and costs associated with procuring high-quality red palm oil from far away. Consumers can be very price sensitive and may be reluctant to change their food preparation and eating habits unless red palm oil or red palm oil–containing products are both affordable and available on a consistent basis. The studies from Burkina Faso allude to the challenges involved in establishing stable and sustainable commercial retail channels for producing, storing, and marketing red palm oil that retains suitable levels of provitamin A activity. In addition, the case study of fortified cassava flour from Tanzania highlights the need to identify and support local processing methods that create products with an acceptable shelf-life. Such issues would be important to consider and plan for before launching programs to introduce red palm oil or red palm oil–containing products into new areas.

There are many potential interventions that can be used to prevent vitamin A deficiency among populations at risk. Choices about launching any new initiatives will be influenced by existing policies and programs and the preferences that key stakeholders have about how limited funds should be spent on micronutrient deficiency control programs. Information about the potential costs and cost-effectiveness of various red palm oil–based interventions appears to be lacking and may present a barrier to expanding the use of red palm oil in the future.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the existing evidence supports the claim that red palm oil–based interventions are efficacious in preventing vitamin A deficiency among populations at risk. Numerous studies have demonstrated that red palm oil–based interventions can improve the vitamin A status of infants, children, and women. Like many other interventions designed to improve vitamin A status, those based on red palm oil are most likely to succeed only in specific settings. Some questions remain about the most appropriate assumptions and conversion factors to use when calculating the vitamin A activity that different types of red palm oil–based interventions can deliver [67]. However, the more urgent need seems to be support for additional operational research projects, effectiveness studies, and cost-benefit analyses (particularly in Africa). This information would provide policy makers and program managers with guidance on how to scale-up proven approaches and potentially expand the use of red palm oil to new settings.

REFERENCES

1. World Health Organization: ''Global Prevalence of Vitamin A Deficiency in Populations at Risk 1995–2005: WHO Global Database on Vitamin A Deficiency.'' Geneva: World Health Organization, 2009.
2. Sommer A, West KP: ''Vitamin A Deficiency: Health, Survival and Vision.'' New York: Oxford University Press, 1996.
3. West KP Jr, Darnton-Hill I: Vitamin A deficiency. In Semba RD, Bloem MW (eds): ''Nutrition and Health in Developing Countries.'' 2nd ed. Totowa, NJ: Humana Press, pp 377–433, 2008.
4. The United Nations Children's Fund (UNICEF): ''Vitamin A Supplementation: A Decade of Progress.'' New York: UNICEF, 2007.
5. de Pee S, West CE: Dietary carotenoids and their role in combating vitamin A deficiency: a review of the literature. Eur J Clin Nutr 50 Suppl 3:S38–S53, 1996.
6. Sundram K, Sambanthamurthi R, Tan YA: Palm fruit chemistry and nutrition. Asia Pacific J Clin Nutr 12:355–362, 2003.
7. Atinmo T, Babre AT: Palm fruit in traditional African food culture. Asia Pacific J Clin Nutr 12:350–354, 2003.
8. World Health Organization: ''Indicators for Assessing Vitamin A Deficiency and Their Application in Monitoring and Evaluating Intervention Programmes, (WHO/NUT/96.10).'' Geneva: World Health Organization, 1996.
9. Institute of Medicine: ''Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc.'' Washington, DC: National Academy Press, 2001.
10. National Research Council (U.S.): ''Recommended Dietary Allowances.'' 10th ed. Washington, DC: National Academy Press, 1989.
11. West CE, Eilander A, van Lieshout M: Consequences of revised estimates of carotenoid bioefficacy for dietary control of vitamin A deficiency in developing countries. J Nutr 132:2920S–2926S, 2002.
12. You CS, Parker RS, Swanson JE: Bioavailability and vitamin A value of carotenes from red palm oil assessed by an extrinsic isotope reference method. Asia Pac J Clin Nutr 11 Suppl 7:S438–S442, 2002.
13. Moore T: Vitamin A and carotene: the vitamin A activity of red palm oil carotene. III. The absence of vitamin D from carotene. IV. The effect of various dietary modifications upon the vitamin A activity of carotene. Biochem J 23:1267–1272, 1929.
14. Ackroyd WR, Wright RE: Red palm oil in the treatment of human keratomalacia. Indian J Med Res 25:7–10, 1937.
15. Oomen HA, McLaren DS, Escapini H: Epidemiology and public health aspects of hypovitaminosis A. A global survey on xerophthalmia. Trop Geogr Med 16:271–315, 1964.
16. Awdry PN, Cobb B, Adams PC: Blindness in the Luapula valley. Cent Afr J Med 13:197–201, 1967.
17. Oomen JM: Xerophthalmia in northern Nigeria. Trop Geogr Med 23:246–249, 1971.
18. Cooper KA, Adelekan DA, Esimai AO, Northrop-Clewes CA, Thurnham DI: Lack of influence of red palm oil on severity of malaria infection in pre-school Nigerian children. Trans R Soc Trop Med Hyg 96:216–223, 2002.
19. Mejía LA, Pineda O: [Replacement of peanut oil used for the fortification of sugar with vitamin A for other vegetable oils available in Central America]. Arch Latinoam Nutr 36:127–134, 1986.
20. Fávaro RM, de Oliveira JE: Enrichment of the diet with synthetic and natural sources of provitamin A. Arch Latinoam Nutr 49:34S–37S, 1999.
21. López de Romaña G, Gross R: IRIS. III: proposal of a multicenter efficacy study using a high-energy, micronutrient-dense spread. Food Nutr Bull 24:S39–S41, 2003.
22. Solomons NW: Alleviation of vitamin A deficiency with palm fruit and its products. Asia Pacific J Clin Nutr 12:373–384, 2003.
23. Scrimshaw NS: Nutritional potential of red palm oil for combating vitamin A deficiency. Food Nutr Bull 21:195–201, 2000.
24. Benadé AJS: The potential of red palm oil–based shortening as a food fortificant for vitamin A in the baking industry. Food Nutr Bull 22:416–418, 2001.
25. Zhang J, Wang CR, Xue AN, Ge KY: Effects of red palm oil on serum lipids and plasma carotenoids level in Chinese male adults. Biomed Environ Sci 16:348–354, 2003.
26. Olmedilla B, Granado F, Southon S, Wright AJ, Blanco I, Gil-Martinez E, van den Berg H, Thurnham D, Corridan B, Chopra M, Hininger I: A European multicentre, placebo-controlled supplementation study with alpha-tocopherol, carotene-rich palm oil, lutein or lycopene: analysis of serum responses. Clin Sci (Lond) 102:447–456, 2002.
27. Roels OA, Djaeni S, Trout ME, Lauw TG, Heath A, Poey SH, Tarwotjo MS, Suhadi B: The effect of protein and fat supplements on vitamin A–deficient Indonesian children. Am J Clin Nutr 12:380–387, 1963.
28. Lian OK, Tie LT, Rose CS, Prawiranegara DD, György P: Red palm oil in the prevention of vitamin A deficiency. A trial on preschool children in Indonesia. Am J Clin Nutr 20:1267–1274, 1967.
29. Lian OK, Tie LT, Rose CS, Prawiranegara DD, György P: Red palm oil in the prevention of vitamin A deficiency. A trial on preschool children in indonesia. Paediatr Indones 8:192–202, 1968.
30. Canfield LM, Kaminsky RG: Red palm oil in the maternal diet improves the vitamin A status of lactating mothers and their infants. Food Nutr Bull 21:144–148, 2000.
31. Canfield LM, Kaminsky RG, Taren DL, Shaw E, Sander JK: Red palm oil in the maternal diet increases provitamin A carotenoids in breastmilk and serum of the mother-infant dyad. Eur J Nutr 40:30–38, 2001.
32. Binns CW, Pust RE, Weinhold DW: Palm oil: a pilot study of its use in a nutrition intervention programme. J Trop Pediatr 30:272–274, 1984.
33. Pust RE, Binns CW, Weinhold DW, Martin JR: Palm oil and pyrantel as child nutrition mass interventions in Papua New Guinea. Trop Geogr Med 37:1–10, 1985.
34. Lietz G, Henry CJ, Mulokozi G, Mugyabuso J, Ballart A, Ndossi G, Lorri W, Tomkins AM: Use of red palm oil for the promotion of maternal vitamin A status. Food Nutr Bull 21:215–218, 2000.
35. Lietz G, Henry CJ, Mulokozi G, Mugyabuso JK, Ballart A, Ndossi GD, Lorri W, Tomkins A: Comparison of the effects of supplemental red palm oil and sunflower oil on maternal vitamin A status. Am J Clin Nutr 74:501–509, 2001.

36. Lietz G, Mulokozi G, Henry JC, Tomkins AM: Xanthophyll and hydrocarbon carotenoid patterns differ in plasma and breast milk of women supplemented with red palm oil during pregnancy and lactation. J Nutr 136:1821–1827, 2006.
37. Radhika MS, Bhaskaram P, Balakrishna N, Ramalakshmi BA: Red palm oil supplementation: a feasible diet-based approach to improve the vitamin A status of pregnant women and their infants. Food Nutr Bull 24:208–217, 2003.
38. Delisle H, Zagré N, Ouedraogo V: Marketing of red palm oil as a food source of vitamin A in Burkina Faso: a pilot project involving women's groups. Food Nutr Bull 22:388–394, 2001.
39. Zagré NM, Delisle H, Tarini A, Delpeuch F: [Changes in vitamin A intake following the social marketing of red palm oil among children and women in Burkina Faso]. Sante 12:38–44, 2002.
40. Zagré NM, Delpeuch F, Traissac P, Delisle H: Red palm oil as a source of vitamin A for mothers and children: impact of a pilot project in Burkina Faso. Public Health Nutr 6:733–742, 2003.
41. Anonymous: Use of carotene-rich foods to combat vitamin A deficiency in India—a multicentric study by the Nutrition Foundation of India: summary and recommendations. Indian Pediatr 34:313–318, 1997.
42. Bhavani KN, Kamini D: Development and acceptability of a ready-to-eat beta-carotene rich, maize based supplementary product. Plant Foods Hum Nutr 52:271–278, 1998.
43. Ghafoorunissa: Nutrition & health implications of palm oil in Indian diets. Indian J Med Res 102:233–240, 1995.
44. Mahapatra S, Manorama R: The protective effect of red palm oil in comparison with massive vitamin A dose in combating vitamin A deficiency in Orissa, India. Asia Pacific J Clin Nutr 6:246–250, 1997.
45. Manorama R, Brahmam GN, Rukmini C: Red palm oil as a source of beta-carotene for combating vitamin A deficiency. Plant Foods Hum Nutr 49:75–82, 1996.
46. Manorama R, Rukmini C: Nutritional evaluation of crude palm oil in rats. Am J Clin Nutr 53:1031S–1033S, 1991.
47. Rao BSN: Palm oil as an edible oil in India and its role in meeting the nutritional needs of its population. Nutr Res 12:S3–S21, 1992.
48. Rao BSN: Palm oil use and compatibility in India. Food Nutr Bull 15, 1994.
49. Rao BSN: Potential use of red palm oil in combating vitamin A deficiency in India. Food Nutr Bull 21:202–211, 2000.
50. Sarojini G, Nirmala G, Geetha R: Introduction of red palm oil into the 'ready to eat' used supplementary feeding programme through ICDS. Indian J Public Health 43:125–131, 1999.
51. Sivan YS, Alwin Jayakumar Y, Arumughan C, Sundaresan A, Jayalekshmy A, Suja KP, Soban Kumar DR, Deepa SS, Damodaran M, Soman CR, Raman Kutty V, Sankara Sarma P: Impact of vitamin A supplementation through different dosages of red palm oil and retinol palmitate on preschool children. J Trop Pediatr 48:24–28, 2002.
52. Sivan YS, Jayakumar YA, Arumughan C, Sundaresan A, Balachandran C, Job J, Deepa SS, Shihina SL, Damodaran M, Soman CR, Raman Kutty V, Sankara Sarma P: Impact of beta-carotene supplementation through red palm. J Trop Pediatr 47:67–72, 2001.
53. van Stuijvenberg ME, Faber M, Dhansay MA, Lombard CJ, Vorster N, Benadé AJS: Red palm oil as a source of beta-carotene in a school biscuit used to address vitamin A deficiency in primary school children. Int J Food Sci Nutr 51 Suppl:S43–S50, 2000.
54. van Stuijvenberg ME, Benadé AJS: South African experience with the use of red palm oil to improve the vitamin A status of primary schoolchildren. Food Nutr Bull 21:212–214, 2000.
55. van Stuijvenberg ME, Dhansay MA, Lombard CJ, Faber M, Benadé AJS: The effect of a biscuit with red palm oil as a source of beta-carotene on the vitamin A status of primary school children: a comparison with beta-carotene from a synthetic source in a randomised controlled trial. Eur J Clin Nutr 55:657–662, 2001.
56. Zeba AN, Martin Prével Y, Some IT, Delisle HF: The positive impact of red palm oil in school meals on vitamin A status: study in Burkina Faso. Nutr J 5:17, 2006.
57. Mosha TC, Laswai HS, Mtebe K, Paulo AB: Control of vitamin A deficiency disorders through fortification of cassava flour with red palm oil: a case study of Kigoma district, Tanzania. Ecol Food Nutr 37:569–593, 1999.
58. Horton S, Alderman H, Rivera JA: ''Copenhagen Consensus 2008 Challenge Paper: Hunger and Malnutrition.'' 2008.
59. The International Bank for Reconstruction and Development/The World Bank: ''Repositioning Nutrition as Central to Development: A Strategy for Large-Scale Action.'' Washington, DC: The World Bank, 2006.
60. HarvestPlus: Breeding Crops for Better Nutrition. Accessed at: http://www.harvestplus.org/ [accessed on 1 May 2010].
61. Stein AJ, Sachdev HPS, Qain M: Genetic engineering for the poor: golden rice and public health in India. World Develop 36:144–158, 2008.
62. Silversides A: Long road to Sprinkles. CMAJ 180:1098, 2009.
63. Plumpy'Nut. Accessed at: http://www.nutriset.fr/index.php?option=com_content&task=view&id=30&Itemid=28 [accessed on 1 May 2010].
64. Aguayo VM, Garnier D, Baker SK: ''Drops of Life: Vitamin A Supplementation for Child Survival Progress and Lessons Learned in West and Central Africa.'' UNICEF Regional Office for West and Central Africa, 2007.
65. Helen Keller International: Working Worldwide. Accessed at: http://www.hki.org/working-worldwide/ [accessed on 1 May 2010].
66. GAIN's Health Programs. Accessed at: http://www.gainhealth.org/programs [accessed on 1 May 2010].
67. Tang G: Bioconversion of dietary provitamin A carotenoids to vitamin A in humans. Am J Clin Nutr 91:1468S–1473S, 2010.

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