Red Palm Oil: A Natural Source of Vitamin A

Radhika Loganathan* and Teng Kim Tiu*

INTRODUCTION

The fruit of the oil palm (*Elaeis guineesis*) yields the oil called red palm oil (RPO). Oil palm is a perennial crop which produces the highest oil yield per hectare per year compared with other leading oilseed crops (Mielke, 2014). Currently, Malaysia and Indonesia are the leading producers of palm oil (Burri, 2012). The oil palm is a unique crop in being able to produce two types of oils, namely crude palm oil from the fibrous mesocarp (which is the brilliant deep red-orange pulp) and palm kernel oil (resembling coconut oil) from the kernel (Sundram *et al*., 2003). Crude palm oil (CPO) can be processed into various downstream products, and this processing partially removes the phytonutrients. Refined, bleached and deodorised (RBD) palm oil, the major processed product, is obtained by bleaching and deodorisation of CPO. During this refining process, the carotenoids which give CPO its red-orange colour, are decomposed, resulting in RBD palm oil having a light yellow colour, while part of the other phytonutrients are still retained in the RBD palm oil (Nagendran *et al*., 2000). RBD palm oil is a versatile oil, widely used in more than 150 countries all over the world (Choo and Nesaretnam, 2014). In contrast, RPO is obtained through a combination of the novel processes of pre-treatment, deacidification and deodorisation using molecular distillation, following which about 80% of the carotenoids and vitamins present in crude palm oil is retained (Nagendran *et al*., 2000). Owing to this special processing technique, RPO has a special flavour and aroma, and is rich in phytonutrients, including carotenoids (which give the oil a bright red colour), vitamin E, phytosterols, squalene and co-enzyme Q10 (Ping and Choo, 2000). Unprocessed RPO has been known for its versatility, both as food and as a health remedy, for centuries. Owing to these benefits, unprocessed RPO was valued as a sacred food by the pharaohs of ancient Egypt (Chawla S, 2013). Unprocessed RPO is also traditionally used in the tropical rain forest regions of West Africa (Burri, 2012) and in north-eastern Brazil (Rice, 2010). Despite the high production and use of refined palm oil in countries like Malaysia and Indonesia, little advantage has been taken of the nutritional potential of RPO (Scrimshaw, 2000). RPO is a virtual powerhouse of nutrition. It is shown to exhibit nutritional properties mainly via its constituent phytonutrients. A list of the phytonutrients present in RPO and their health benefits are given in *Table 1**. The current review focuses on the health benefits of RPO supplementation in overcoming vitamin A deficiency in children and pregnant women.

BIOAVAILABILITY AND BIODISTRIBUTION OF RED PALM OIL

Vitamin A occurs naturally in animal products. Good sources of vitamin A are cheese, butter, eggs, liver and fish (Solomons and Bulux, 1997). Vegetarians get their required vitamin A from carotenoids, which are found in plants, especially in orange, green and yellow vegetables as well as some fruits (Sommer, 1995). RPO is considered one of the world's richest natural plant sources of carotenoids which are responsible for the brilliant orange-red colour of the oil and fruit (Sommer, 1995). About 600 types of naturally occurring carotenoids are known (Deming and Erdman, 1999). Thirteen different types of carotenoids are found in palm oil, namely phytoene, phytofluene, *cis*-β-carotene, β-carotene, α-carotene, *cis*-α-carotene, ζ-carotene, γ-carotene, δ-carotene, neurosporene, β-zea-carotene, α-zeacarotene and lycopene (Ping and Choo, 2000). The major carotenes are β-carotene and α-carotene, accounting for 41.0% and 41.3%, respectively, of the total carotenoids present in commercial RPO (Ping and Choo, 2000). Of the 600 known carotenoids, only 10% is believed to have provitamin A activity. The α-, β- and γ-carotenes are quantitatively the only carotenes of RPO that show provitamin A activity (Loganathan *et al*., 2010). RPO has 15 times more retinol (provitamin A) equivalents than carrot, 300 times more than tomato (Nagendran *et al.*, 2000) and 44 times more than leafy vegetables (Scrimshaw, 2000).

* Malaysian Palm Oil Board (MPOB),
6, Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.
E-mail: radhika@mpob.gov.my

* We recently published a comprehensive review on the nutritional aspects of RPO (Loganathan *et al.*, 2017).

TABLE 1. HEALTH BENEFITS OF PHYTONUTRIENTS FOUND IN RED PALM OIL

Palm phytonutrient	Health benefits
Vitamin E (717-863 ppm)	*Composition: α-tocopherol (19%), α-tocotrienol (29%), γ-tocotrienol (41%), δ-tocotrienol (10%) Health benefits: • Anti-cancer • Anti-angiogenesis • Antioxidant activity • Anti-arthrosclerosis • Inhibition of cholesterol synthesis • Cardio-protection • Diabetes management • Neuroprotection
Carotenoids (600-750 ppm)	*Composition: phytoene (0.2%), phytofluene (0.6%), β-carotene (41.0%), α-carotene (41.3%), *cis*-α-carotene (10.2%), ζ-carotene (0.6%), γ-carotene (0.8%), δ-carotene (0.8%), neurosporene (0.2%), β-zeacarotene (1.3%), α-zeacarotene (0.5%), lycopene (1.0%) Health benefits: • Provitamin A activity • Cardio-protection • Anti-cancer • Prevention of night blindness
Phytosterols (325-365 ppm)	*Composition: cholesterol (6.6-11.5 ppm), campesterol (76-83 ppm), stigmasterol (59-64 ppm), β-sitosterol (187-218 ppm), unknown (<6 ppm) Health benefits: • Cholesterol lowering properties • Anti-cancer • Enhancement of immune functions
Squalene (14-15 ppm)	*Composition: squalene (14-15 ppm) Health benefits: • Cardio-protection • Inhibition of cholesterol synthesis • Anti-cancer • Radioprotection
Ubiquinone (18-25 ppm)	*Composition: co-enzyme Q10 (18-25 ppm) Health benefits: • Enhanced production of cellular energy • Antioxidative defence mechanism • Cardio-protection • Anti-cancer

Note: *ppm: parts per million (Ping and Choo, 2000). Source: Adapted from (Loganathan *et al.*, 2010).

Carotenoids are fat-soluble pigments which require fat for conversion into vitamin A. Both vitamin A and β-carotene are absorbed in the small intestine along with fats, in the presence of bile and pancreatic secretions (Deming and Erdman, 1999; Van Het Hof *et al.*, 2000). Bioavailability of β-carotene and vitamin A is greater with the simultaneous intake of fats (Van Het Hof *et al.*, 2000). A minimum of 5 g of fat is required for optimal absorption of carotenoids (Deming and Erdman, 1999). Thus, RPO is the perfect solution for the treatment of vitamin A deficiency. In humans, the half-life of vitamin A is 200-300 days (Tolonen, 1990); hence, vitamin A balance is not disturbed by slight fluctuations in its consumption. Ninety percent of stored vitamin A is located in the liver, 1.5% is found in blood and the remainder is stored in other tissues. The β-carotene, on the other hand, returns to baseline levels within 20 to 30 days upon cessation of supplementation (Tolonen, 1990). Provitamin A carotenoids in RPO are found to be highly bioavailable, efficiently converted to retinols and store well in the liver.

SAFETY, MUTAGENECITY AND TOXICOLOGY

The safety of crude and RBD palm oils has been extensively studied, and no adverse effect was found in mutagenicity, nutritional and toxicological studies. Mutagenicity tests were conducted on repeatedly-heated crude and refined palm oils to test for safety of edibility. In the Ames bacterial system, using *Salmonella typhimurium* strains TA100 and TA98, no mutagens were detected when extracts of these oils were metabolically activated using the S9 fraction of rat liver microsomes (Manorama *et al*., 1989). When fats are subjected to heat, thermal oxidation and formation of mutagens take place. Heating can also lead to deterioration of the quality and wholesomeness of the oil. This study proved that these oils are suitable to be used as a frying medium. In addition, despite repeated frying, the oils were found to possess chemical stability and remained safe for consumption (Manorama *et al*., 1989). RPO protection against chemical carcinogens was found to be due likely to its carotenoid content (Manorama *et al*., 1993). In a seven-week animal study, the tolerance and effective antioxidant potential of ordered doses (0, 1, 2 or 4 ml) of RPO was studied. RPO supplementation was found to enhance the concentration of antioxidants in red blood cells and liver. Additionally, animals fed on RPO had normal liver construction. Based on the data available, it may be concluded that RPO is safe for consumption and for use as supplementation (Ayeleso *et al*., 2014).

RECOMMENDED DIETARY ALLOWANCE (RDA) OF VITAMIN A AND RECOMMENDED RPO SUPPLEMENTATION

The total amount of vitamin A in food is expressed as micrograms of retinol equivalents (RE). Hundred grams of RPO is equivalent to approximately 7000 RE. The RDA of vitamin A by age group and gender as set by the Institute of Medicine (IOM) of the National Academies of USA (Institute of Medicine, 2001) are represented in *Table 2*. An estimated one teaspoon (5 g) of RPO will supply RDA of vitamin A for an infant and child, whereas double this amount (10 g) will supply RDA for an adult and pregnant woman, with the highest requirement being for a lactating woman at ~18 g. The contribution of phytonutrients according to the estimated recommended amount of RPO is shown in *Table 3*. Based on a comprehensive review of 62 controlled trials, the correlation between health outcome and plasma concentration was studied, and a carotenoid health index was proposed with five category scales: <1 μM (very high risk), 1-1.5 μM (high risk), 1.5-2.5 μM (moderate risk), 2.5-4 μM (low risk) and >4 μM (very low risk) (Donaldson, 2011).

RED PALM OIL AND VITAMIN A DEFICIENCY

Extensive research has been conducted on the health impact and therapeutic efficacy of RPO on various diseases. Supplementing RPO for vitamin A deficiency, in particular, has been extensively studied in children, pregnant women and lactating mothers.

Deficiency of vitamin A or retinol is a public health problem and is listed as the most widespread nutritional deficiency worldwide (Sommer, 1995). Inadequate vitamin A-rich food intake, fat malabsorption or liver disorders lead to vitamin A deficiency. Provitamin A can be cleaved to yield retinaldehyde, and thence to retinol and retinoic acid (Rao, 2000).

Children

According to the World Health Organisation (WHO), about 190 million pre-school children in underdeveloped countries, especially in the regions of Africa and South-East Asia, are vitamin A-deficient (WHO, 2011). Infants and children require more vitamin A to promote rapid growth and better immunity to combat infections. Vitamin A deficiency in children causes visual impairment and blindness, the risk of infection, stunting, anemia, respiratory diseases and mortality due to common childhood infections such as diarrhea and measles. On the basis on the Cochrane meta-analysis on 194 795 children, vitamin A supplementation could reduce childhood mortality by 23% as well as incidences of illnesses (Imdad *et al.*, 2010).

In South Africa, Stuijvenberg *et al.* (2000) compared the effect of supplementation with β-carotene-fortified biscuits containing either RPO as a source of β-carotene or synthetic β-carotene (both provided 1.43 mg β-carotene, equivalent to 34% of RDA of vitamin A for children), with a placebo as a control, on the vitamin A status of primary school children. Biscuits were distributed on school days to a total of 265 primary school children aged between 5 and 11 years, from the rural Noqomfela primary school, KwaZulu-Natal, over six months. Increase in serum retinol levels from baseline to six months was identical in all three groups. The authors reported two confounding factors in the

TABLE 2. RECOMMENDED DIETARY ALLOWANCE (RDA) OF VITAMIN A BY INSTITUTE OF MEDICINE (IOM)

Category	Age	Vitamin A (μg RE)	Recommended RPO supplementation (g)
Infants	0-12 months old	400-500	5.7-7.1
Children	1-8 years old	300-400	4.3-5.7
Adults			
- Males	9-70 years old	600-900	8.6-12.9
- Females	9-70 years old	600-700	8.6-10
Pregnancy	14-50 years old	750-770	10.7-11
Lactation	14-50 years old	1 200-1 300	17.1-18.6

Note: RPO - red palm oil.
Source: Adapted from (Institute of Medicine, 2001).

TABLE 3. CONTRIBUTION OF PHYTONUTRIENTS ACCORDING TO ESTIMATED RECOMMENDED AMOUNT OF RED PALM OIL (RPO)

Phytonutrient component	Amount in grams		
	5 g of RPO (1 teaspoon)	10 g of RPO (2 teaspoon)	18 g of RPO (1 tablespoon)
Total carotene	3.3	6.7	12.0
*β-carotene	1.3	2.7	4.8
*α-carotene	1.3	2.7	4.8
*Other carotenes	0.7	1.3	2.4
Total vitamin E	4.1	8.1	14.6
*α-tocopherol	0.8	1.5	2.8
*α-tocotrienol	1.2	2.3	4.2
*γ-tocotrienol	1.7	3.3	6.0
*δ-tocotrienol	0.4	0.8	1.4
Co-enzyme Q10	0.1	0.2	0.4
Phytosterols	1.6	3.2	5.8
*Campesterol	0.2	0.5	0.9
*Stigmasterol	0.3	0.6	1.1
*β-sitosterol	1.0	2.0	3.6
*Cholesterol and unknown	0.0	0.1	0.2

Source: Adapted from Ping and Choo (2000).

observations. Firstly, a new school lunch programme was introduced during the last four weeks of the study duration (providing 233 μg RE of β-carotene/day, or 33% of the RDA of vitamin A). Secondly, the last batch of RPO-fortified biscuits provided only half of the intended RDA of vitamin A due to degradation of the RPO shortening resulting from unsuitable storage conditions (van Stuijvenberg *et al*., 2000). However, this study reported that the RPO-fortified biscuits were well accepted, and hence suggests they are a feasible approach for tackling vitamin A deficiency among children (van Stuijvenberg *et al*., 2000, van Stuijvenberg *et al*., 2001). A follow-up study covering a new area with no school lunch program to confound the results, has been reported (van Stuijvenberg *et al.*, 2001, Van Stuijvenberg and Benadé, 2000). A similar experimental design was employed but with a slightly lower dose per day, satisfying 30% RDA of vitamin A on a larger number of students (n=432) aged between 5 and 11 years from rural Ndunakazi and Intongela primary schools in KwaZulu-Natal, for a shorter duration of three months. Provitamin A status improved to a similar extent for β-carotene-fortified biscuits using either RPO or synthetic β-carotene (van Stuijvenberg *et al.*, 2001).

In Burkina Faso, the benefit of adding RPO in school meals on vitamin A status was studied in primary schools in the Kaya (north-central part) and Bogande (eastern part) areas of Burkina Faso. The sites were carefully chosen so as not to have interference of RPO in the supplementation programme nor in its production. In Kaya, 239 pupils (7-12 years old) from 15 intervention schools followed a pre-post test to gauge the effect of RPO supplementation on serum retinol. The 15 ml of RPO (15 000 μg RAE) per individual was incorporated into the school lunch program, three times a week for one year. Serum retinol increased while the rate of low serum retinol level declined after 12 months of feeding. In Bogande, there were three groups, namely Group 1-the negative control fed with the regular school lunch, Group 2-the positive control receiving the regular school lunch and a single vitamin A capsule (60 mg) at the end of the school period, and Group 3-receiving RPO (totalling 76.5 μg RAE over the test period). A comparable improvement in serum retinol level and a decline in the rate of low serum retinol level were reported in both Groups 2 and 3. Therefore, it appears that a regular small amount of RPO is beneficial for countering vitamin A deficiency (Zeba *et al*., 2006).

In India, Manorama *et al.* (1996) conducted three studies aimed at evaluating the pre-post test effect of RPO on retinol level, to assess the efficiency of RPO as a vitamin A supplement, and to determine the sustainability of serum retinol level over a period of non-supplementation with RPO compared to supplementation with vitamin A. In the first trial, vitamin A-deficient children (n=24) aged between 7 and 9 years, from a low socio-economic group in a government-aided home in Hyderabad, were given the Indian sweet *suji halwa* fortified with RPO (2400 μg β-carotene), or prepared with groundnut oil with oral supplementation of 600 μg of vitamin A, as evening snacks for two months. Improvement of a similar magnitude was observed in the RPO and synthetic vitamin A-supplemented groups for serum retinol level and liver retinol store. In the second trial, mild to severe vitamin A-deficient children (n=26) aged between 7 and 12 years from government schools in Hyderabad, were given evening snacks similar to those in the first trial but also with a massive single dose of synthetic vitamin A (100 000 IU) over a shorter duration of one month. A two-fold improvement in serum retinol level was reported in both groups. In addition, although the baseline level of β-carotene was low in both groups, the RPO-fortified group showed more than a three-fold improvement in β-carotene level. In the third trial, vitamin A-deficient children (n=36) aged 7 to 9 years from an interior village in Nakhaur, Orissa, were subjected to one-month dietary supplementation, and called for a follow-up examination after six months. The children were assigned to three groups, receiving either the control with 100 000 IU vitamin A in a single massive dose, or RPO-fortified Indian sweet '*Besan laddhu*' at either 4 g of RPO (50 000 IU of vitamin A), or 8 g of RPO (100 000 IU of vitamin A). Six months after cessation of supplementation, it was found that snacks fortified with 8 g RPO conferred a comparable retinol level as the control group receiving a massive dose of vitamin A (Manorama *et al*., 1997). RPO is an efficient source of bioavailable β-carotene; hence, an intervallic RPO supplementation twice or thrice a year is recommended to maintain an adequate vitamin A status (Manorama *et al.*, 1996).

Like the earlier study, a comparison between supplementation with a massive vitamin A dose (50 000 IU) and with RPO-fortified Indian sweet b*esan laddhu* at either 4 g (25 000 IU) or 8 g RPO (50 000 IU) for a shorter duration of 15 days was conducted on children (n=36) aged between 7 and 9 years in Nakhour village, Orissa. Serum retinol levels were evaluated at baseline, 15 days upon supplementation and three months post-supplementation. A massive dose of vitamin A and the snack fortified with 4 g of RPO doubled retinol level recorded at baseline, whereas the snack with 8 g of RPO tripled the amount of retinol. Furthermore, 8 g of RPO was adequate to confer similar protection as the massive vitamin A dose upon supplementation and in the post-supplementation period. Rather than the practice of regular feeding, a periodic feeding approach at regular three monthly intervals was suggested for supplementary feeding programs to maintain normal childhood vitamin A nutriture (Mahapatra and Manorama, 1997).

Pregnancy and Lactation

According to WHO, about 19 million pregnant women are vitamin A-deficient in underdeveloped countries, especially in Africa and South-East Asia (WHO, 2011). During pregnancy and lactation, women are vulnerable to vitamin A deficiency because additional vitamin A is required to support maternal and fetal tissue growth and to replace lactation losses (Joint FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements, 2004). Lactating mothers are encouraged to supplement their diet with carotenoid-rich RPO to promote an increase in retinols in maternal serum or breast milk (Lietz *et al*., 2000).

The impact on vitamin A status by supplementation with 8 ml RPO (2400 μg of b-carotene) or groundnut oil in sachets was studied on pregnant women (n=170) and infants. Mothers-to-be recruited from Niloufer Hospital, Hyderabad, followed eight weeks of supplementation from 26-28 weeks to 35-36 weeks of gestation. Subsequently, higher retinol levels in mothers and infants, with lower incidence of maternal anemia, were reported (Radhika *et al*., 2003).

Lietz *et al.* (2001) conducted two studies on provitamin A activity of RPO among pregnant and lactating women in drought-prone rural villages of Tanzania. In the first study, pregnant women in their third trimester were allocated to receive either RPO (12 g per day), sunflower oil (12 g per day) or staple food, and encouraged to maintain their practice of eating dark green vegetables. Tanzanian staple foods comprise sorghum, millet, maize, sweet potato, legumes and green vegetables, whereas fish, meat and eggs are rarely eaten. Sufficient oil according to household size was provided for six months from the beginning of the third trimester to three months postpartum. Increases in provitamin A activity as shown by α-carotene and β-carotene levels were found in both breast milk and plasma from the RPO-supplemented group. Retinol levels in breast milk were maintained in both sunflower oil- and RPO-supplemented groups (Lietz *et al*., 2001).

In the second follow-up study with a similar study design, carotenoid patterns in both plasma and breast milk were studied. Hydrocarbon carotenoids (α-carotene and β-carotene) were comparatively higher and xanthophylls (lutein and zeaxanthin) were comparatively lower in plasma compared with breast milk in the RPO-supplemented group. Appreciable amounts of provitamin A and xanthophylls in breast milk for nursing infants were found in the RPO-supplemented group. Xanthophylls are present in the eye's macular pigment and serve as a photoreceptor protector against photooxidative damage (Lietz *et al*., 2006).

In another similar study design, also on pregnant Tanzanian women in their third trimester, the effects of dietary RPO, sunflower oil or staple food on milk cytokines and prevalence of subclinical breast inflammation were investigated. Mothers were encouraged to breastfeed as breast milk is rich with immunologically active components that can promote infant health and immunity. A significant decrease in milk Na/K ratio was found in the sunflower oil group compared with the RPO-supplemented group. The limitations of the study were that it was not randomised or double-blinded (Filteau *et al.*, 1999).

In a short-term 10-day study, Honduran mother-infant pairs (n=98) were assigned to receive either RPO supplementation (15 ml equivalent to 15 mg β-carotene and 6.8 mg α-carotene), β-carotene supplements (15 mg) or a placebo (corn starch). Short-term RPO intake in the maternal diet was found to increase α- and β-carotenes in maternal plasma and breast milk. A significant increase in β-carotene compared to α-carotene was found in infant plasma. An improvement in vitamin A status in mother-infant diet with the possible metabolism of β-carotene to retinols by mother/infant, or higher bio-availability of α-carotene, was suggested (Canfield *et al*., 2001).

A survey was conducted on pregnant Nigerian women at different stages of pregnancy (n=200) to determine any correlations between vitamin A status, habitual diet, present health and morbidity status. Four-fifths of the subjects were reported to consume RPO. It is speculated that high episodes of malaria, anemia and incidence of subclinical infections, such as upper respiratory and urinary tract infections, occurred in conjunction with a high prevalence of vitamin A deficiency. In addition, the method of food preparation, involving application of high heat to the oil up to the point of smoking for a minimum 10 min before stewing, green vegetables being boiled before addition to a sauce, and low consumption of liver (~3 days per month), may relate to the low viable vitamin A. This study indicates vitamin A deficiency is still prevalent in pregnant Nigerian women (Ajose *et al*., 2004). Education in food preparation and heat stability of RPO may be beneficial to this group.

A study using a longitudinal pre-post intervention design was undertaken to evaluate the effectiveness of RPO as a source of vitamin A in a non-consuming area of Burkina Faso among mother-child (1-3 years old) pairs (n=210). Breast milk, RPO consumption and fruits contributed to a significant increase in dietary vitamin A among children, whereas RPO intake and vegetables significantly increased dietary vitamin A among mothers. RPO can significantly increase serum retinol levels in both mothers and children (Zagre *et al*., 2003).

Mosha *et al.* (1998) conducted a study as part of an on-going effort to produce vitamin A-enriched staples locally. The local staple, cassava flour, was fortified with under utilised RPO. RPO-fortified cassava flour (1920 RE per day) was then used to prepare weaning food and normal family meals that were given to pre-school children (n=162) as well as to pregnant and lactating women (n=68). The 20-month pilot study was conducted in five villages in the Kigoma rural district of Tanzania, which had high incidences of vitamin A deficiency disorders and undernourishment problems. Although Kigoma district is among the largest producers of RPO, the oil is under utilised due to a lack of nutritional awareness by mothers and to its unacceptable flavour, especially to children. In three pilot villages, community-level nutrition education programmes were conducted to train mothers to prepare RPO-fortified cassava flour. The remaining two villages served as the control, practicing the traditional way of cassava consumption, *i.e.* they did not participate in the cassava flour fortification programme and the feeding trials. RPO-fortified cassava flour was reported to be highly acceptable. Feeding with the fortified cassava flour was found to improve serum retinols level and growth rate among pre-school children. Serum retinol concentrations also increased in pregnant and lactating women. Hence, fortification of a staple food with RPO can be a cheap, feasible and practical way to address the vitamin A deficiency issue (Mosha, 1998).

A cluster-randomised cross-sectional dietary intake survey was conducted among 587 households of mother-child dyads to assess the prevalence of vitamin A deficiency in Akwa Ibom, Nigeria. This assessment was part of a HarvestPlus programme aimed at introducing provitamin A-biofortified cassava as sustainable food farming in Nigeria. Subjects were reported to have iron deficiency as indicated by low ferritin and high transferrin levels. This population was found to have adequate vitamin A due to relatively high RPO consumption frequency accounting for nearly 50%-60% of the daily vitamin A intake. However, vitamin A deficiency prevalence among the children is a still a moderate concern. According to the author, this could relate to several factors like infection status, efficiency of provitamin A bioconversion from the diet, and degradation. Subjects had higher levels of retinol carrier, namely retinol-binding protein, compared to serum retinol levels, indicating adequate retinol liver stores (De Moura *et al*., 2015).

Vision Impairment Due to Vitamin A Deficiency in Children

According to WHO, an estimated 2.8 million pre-school-aged children are at risk of nutritional blindness or active xerophthalmia due to vitamin A deficiency in low-income countries (WHO, 2010). Sadly, approximately 250 000 to 500 000 children suffering from vitamin A deficiency become blind yearly, and half of the number die within a year of losing their vision (WHO, 2010). The different eye signs of vitamin A deficiency (VAD) in children as graded by WHO are night blindness, conjunctival xerosis, Bitot's spots, corneal xerosis, corneal ulcer/ keratomalacia and corneal scarring (Sommer, 1995). Severe vitamin A deficiency distresses ocular tissue by reducing regeneration of the visual pigment upon exposure to bright light, or producing lasting damage to the epithelium of the cornea and conjunctiva. Classical ocular manifestation due to vitamin A deficiency may lead to the less serious Bitot's spots and night blindness, or severe xerophthalmia and keratomalacia leading to blindness (Scrimshaw, 2000).

In a 1937 hospital-based study, Aykroyd and Wright (Aykroyd and Wright, 1937) conducted a study to determine the effects of RPO emulsion compared to cod liver oil emulsion (both supplying 500 IU per day) in infants and children with keratomalacia or corneal ulceration. RPO showed a 60% higher vitamin A activity compared to cod liver oil. An assured improvement with RPO treatment was found within a fortnight. Comparable results were attained with both treatments. RPO was found to be better tolerated than cod liver oil which tended to aggravate diarrhea. In terms of palatability, RPO was reported to be better (Aykroyd and Wright, 1937).

Two studies conducted in India reported a reduction in Bitot's spots. Bitot's spots are areas with abnormal squamous cell proliferation and keratinization of the conjunctiva leading to the formation of patches. In the first study, Sivan *et al.* (2001) studied the effects of RPO-fortified noon meals on vitamin A and morbidity status, as well as acceptability of RPO. Pre-school children (n=923) from 35 daycare centers of the Vivekananda Kendra Rural Development Programme, Tamil Nadu, India were chosen based on regions with high prevalence of xerophthalmia. Standard noon meals fortified with either 5 ml of RPO or groundnut oil were provided for 10 months. The RPO-fed group had better vitamin A status, and showed an improvement in Bitot's spots disappearance and incidence, higher serum β-carotene levels, and demonstrated equal acceptability compared to the control group (Sivan, 2001). In a follow-up study, a shorter intervention of seven months was undertaken with the addition of control groups with vitamin A retinol palmitate (400 RE or 800 RE), groundnut oil (5 ml and 10 ml) and experimental groups with RPO (5 ml=400 RE or 10 ml=800 RE). The six groups covering a smaller number (n=334) of pre-school children from the Vivekananda Kendra pre-school of Ramanathapuram, Tamil Nadu, were recruited to assess the effectiveness of RPO and to determine the optimal supplementation dose. Sivan *et al.* (2002) reported that the lower dose of 5 ml of RPO per day was adequate to produce an improvement in vitamin A protection compared to the 8 ml used by Mahapatra and Manorama (1997). The 5 ml of RPO a day is reported to be sufficient to improve retinol, β-carotene and α-tocopherol status. In addition, RPO conferred better protection than the synthetic vitamin A group, and both groups reported no new Bitot's spot cases (Sivan *et al*., 2002).

A multicentric study was conducted by the Nutrition Foundation of India at three centres, namely Trivandrum, Coimbatore and New Delhi. Although initially the subjects did not like the odour and colour of RPO, it was eventually well accepted by children, pregnant and lactating women. RPO supplementation was found to increase the rate of disappearance of Bitot's spots in Coimbatore and Trivandrum. In New Delhi, RPO was found to significantly improve conjunctival impression cytology. In addition, 54% of the children suffering from conjunctival impression cytology were pronounced normal after six months of RPO supplementation. After five months of supplementation, 80% of the subjects with vitamin A deficiency were found to have normal vitamin A levels. Hence, a small amount of RPO (4 to 10 g per day) is found to be adequate to improve vitamin A status in children and adults (Seshadri, 1997).

Ocular manifestation of vitamin A deficiency still exists in underprivileged communities in Malaysia (Ngah *et al.*, 2002). Vitamin A deficiency is prevalent in pre-school and primary schoolchildren of aborigines and communities from rubber estates. The acceptability and order of preference of three different RPO-fortified local snacks, namely spring roll, curry puff and doughnut, were tested on 26 pre-school children from two pre-schools in an aboriginal settlement in Sungai Tekir, Negeri Sembilan, Malaysia. The snack was incorporated with 5 ml of RPO (300 RE) a day that contributed two-thirds of Recommended Nutrient Intakes for vitamin A in Malaysian children. Carotenoid retention in the snacks varied (100% in doughnut, 84% in spring roll and 35% in curry puff), according to the different heating conditions during preparation of the snacks preparation. Acceptability of all snacks was high (82%-100%). The children preferred spring roll the most and doughnut the least (Ng *et al*., 2012). RPO-fortified snacks can be used to combat the vitamin A deficiency problem among aboriginal (Ng *et al.*, 2012) and underprivileged children in Malaysia.

Back in 1963, a study was conducted on Indonesian boys (n=52), aged between 3 and 13 years who had obvious eye symptoms of vitamin A deficiency and minor symptoms of xerophthalmia; the boys were from orphanages in Jakarta in Java. The children were assigned to five groups receiving sugar (2 g kg^{-1} body weight), skim milk powder (2 g kg^{-1} body weight), coconut oil (1 g kg^{-1} body weight), RPO (410 µg β-carotene/kg body weight) or 2000 IU vitamin A acetate for 22 days during mealtimes. Remarkably, RPO was found to cure night blindness in these children. Compared to other groups, supplementation with RPO was also able to raise serum vitamin A levels after one week of supplementation, and the effect could be sustained thereafter (Roels *et al*., 1963).

In 1967, Lian *et al.* (1968) conducted a study to improve vitamin A intake in pre-school children (n=226) aged between 1 and 5 years with xerophthalmia in five Javanese villages. Villages 1 and 2 were assigned to receive RPO as a vitamin 'medicine' (4 ml per day = 3000 units of provitamin A), Village 3 was assigned to receive RBD palm oil, Village 4 received no supplement and Village 5 was supplemented with skim milk fortified with vitamins A and D (2400 IU vitamin A) for two weeks. Interestingly, the villages supplemented with RPO had a reduction in xerophthalmia incidence and an increase in vitamin A level. In addition, children supplemented with skim milk fortified with vitamin A showed an increase in serum vitamin A, indicating vitamin A can be absorbed even on a diet low in fat (Lian *et al*., 1968).

CONCLUSION

RPO is a rich potion of phytonutrients among which are tocotrienols, tocopherols, carotenoids, phytosterols, squalene and coenzyme Q10. Reviewing the literature of RPO's superior health benefits has provided a platform to better understand this wholesome oil. RPO is found to have highly bioavailable β-carotene and provitamin A, is reasonably stable to heat without any adverse effects on mutagenicity, in nutritional and toxicological studies. Daily supplementation with a few teaspoons is adequate to confer protection against various health ailments and maintain well-being in life. Promising data are available on the bioavailability of RPO, hence conferring efficacy in combating vitamin A deficiency among children and pregnant women.

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