A review on vitamin A deficiency and depleted immunity in South Asia: from deficiency to resilience

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Review

A review on vitamin A deficiency and depleted immunity in South Asia: From deficiency to resilience

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ABSTRACT

In the developing world, the twin challenges of depleted health and growing issue of food waste management loom large, demanding simultaneous attention and innovative solutions. This review explores how these issues can be effectively mitigated while shedding light on the transformative impact of food waste valorization on health management. A spotlight is cast on vitamin A deficiency (VAD), an acute public health concern, especially prevalent in South Asia, driven by economic constraints, sociocultural factors, inadequate diets, and poor nutrient absorption. VAD's devastating effects are exacerbated by limited education, lack of sanitation, ineffective food regulations, and fragile monitoring systems, disproportionately affecting children and women of childbearing age. Recent studies in South Asian countries have revealed rising rates of illness and death, notably among children and women of childbearing age, due to VAD. To address inadequate dietary intake in children utilizing vegetable waste, particularly from carrots and beetroot, which are rich in β-carotene, and betalains, respectively, offers a sustainable solution. Extracting these compounds from vegetable waste for supplementation, fortification, and dietary diversification could significantly improve public health, addressing both food waste and health disparities economically. This approach presents a compelling avenue for exploration and implementation. In summary, this review presents an integrated approach to tackle health and food waste challenges in the developing world. By tapping into the nutritional treasure troves within vegetable waste, we can enhance health outcomes while addressing food waste, forging a brighter and healthier future for communities in need.

Introduction

Vitamin A (VA), also known as retinol, plays a crucial role in human physiology [1], and maintains innate immunity, defense against infections, and growth promotion [2,3]. It also protects against night blindness, a common issue in young children and pregnant women. The main sources of VA include meat products, dairy products, and plants like fruits and vegetables [2,4,5]. Provitamin A (PVA), a precursor to VA, is primarily found in leafy vegetables and yellow fruits [4,6]. Currently, the health status of pregnant women, lactating mothers, newborns, and young children below the age of 5 to 6 have recorded the highest mortality, morbidity, blindness, and sickness rate due to the vitamin A deficiency (VAD) and depleted immunity [6,7]. To collect such health-related information in India from different sections of the population by sex, caste, creed and age, the government conducts the National Family Health Survey (NFHS) every 4 y. The NFHS-5 phase 1 survey in India revealed that 16 out of 22 states have increased malnutrition, VAD, and iron deficiency rates compared to NHFS-4. The report also suggests that the government needs to rethink its nutritional programs to meet nutritional targets for the coming decade. The immunization ratios are only 70% against infections and diseases. VA and iron deficiency are prevalent among pregnant, lactating women and young children, leading to reduced immunity, anemia, and mortality risk [8–11].

Pakistan also grapples with severe subclinical VAD, contributing to child mortality, especially in cases of diarrhea and pneumonia [12]. Measles-affected children in Pakistan are concurrently experiencing VAD [12], emphasizing the need for effective VA supplementation. Karachi city reported avoidable cases of child blindness [13], with a majority preventable by meeting the daily requirement of VA. Sri Lanka and Bangladesh also face significant challenges, with studies indicating widespread VAD among preschool children and pregnant women, respectively [14]. In

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Bangladesh, 51% of pregnant women had dietary deficiencies, leading to 18.5% exhibiting VAD [8]. Addressing the pervasive nature of VAD requires a multifaceted approach, including awareness campaigns, dietary diversification, fortification programs, and enhanced healthcare infrastructure in South Asian countries. The data underscore the urgency of comprehensive strategies to combat VAD and its adverse effects on public health in the region.

On the other hand, vegetable waste represents a significant global challenge, with staggering facts and figures highlighting the scale of the issue. Each year, it is estimated that approximately one-third of all food produced for human consumption, which includes a substantial portion of vegetables, goes to waste. This amounts to over 1.3 billion metric tons of food wasted annually, with vegetables comprising a substantial portion of this figure that is approximately 30% [15,16]. Beyond the immense environmental toll, as food waste generates substantial greenhouse gas emissions, it also poses a severe economic burden, with food waste costs reaching hundreds of billions of dollars each year. Vegetable waste is particularly concerning due to its role in perpetuating malnutrition, as the discarded portions often contain valuable nutrients and bioactive compounds like β-carotene, as well as the potential to alleviate VAD in many regions [17,18]. Consequently, addressing the issue of vegetable waste on a global scale is not only an environmental imperative but also a crucial step toward improving food security and public health worldwide [19,20]. The volume of vegetables wasted in the India and neighboring countries, per capita per household, is immense and it is more than 50% of total [21]. The need to utilize the waste must therefore be explored. Simultaneously, it is also necessary to ensure that the utilization process is economically viable. Unfortunately, there are many utilization routes described in published literature, but there are no studies examining economic viability. It is therefore difficult to justify a specific waste utilization approach—be it in terms of fortification of food or any waste valorization option. The feasibility of fortification is rooted in comprehending the diversity of food vehicles, and ensuring technological adaptability to existing production processes, and seamless integration into supply chains. Simultaneously, resilient waste valorization relies on the identification of viable waste streams, economic feasibility, and compliance with regulatory standards. The economic sustainability of fortification is crucial, encompassing cost-effective nutrient addition, affordability for end consumers, and an evaluation of the long-term financial impact. By harmonizing these factors, a resilient approach ensures that fortification and waste valorization strategies not only align with industrial structures but also contribute to sustainable health outcomes and the economic viability of the food industry [22].

Hence, these leading malnutrition and depleted health status related problems can be mitigated by the use of bioactive components found in various food sources such as β-carotene as a precursor of VA and betalains. β-carotene derived from natural sources undergoes conversion into two molecules of vitamin A within the animal body, subsequently storing it as retinyl ester. Similarly, the obtained betalains from beetroot waste can improve heart health, blood pressure, some types of cancer, hyperlipidemia and also acts as an antioxidant and one of the most sought pigments in several industries [23–25]. The bioavailability of betalains is well proven to mitigate the heart and blood pressure associated with beetroot juice consumption [26]. Considering the current status of heart-related and other cancerous diseases on rise in South Asian countries, it was also justified to incorporate them in this review [27]. In addition, the amount of waste created from fresh produced beetroot was one of the factors for its addition in this review [28].

The primary aims and objectives of this review are to underscore the significant dual challenge posed by food waste, particularly vegetable waste, and the widespread issue of VAD and weakened immunity, prevalent in Asian and other developing countries. We aim to emphasize the often-overlooked opportunity for solving both problems simultaneously by taking a scientific approach to the valorization of vegetable waste. Through this review, we intend to establish the scientific foundation for this approach, shedding light on how vegetable waste, such as beetroot and carrot remnants, which is rich in bioactive compounds like β-carotene and betalains, holds the potential to combat nutritional deficiencies, ultimately enhancing public health. By reviewing existing research, proposing sustainable solutions, and raising awareness about the importance of integrating food waste management and nutritional strategies, our review seeks to inspire further research in this crucial area and encourage future endeavors to delve deeper into the valorization of vegetable waste for holistic health and environmental sustainability.

Methodology

A literature search was conducted with following key words such as VAD, Vitamin A precursors, Vitamin A, Waste valorization, Food waste valorization, vegetable waste valorization, health status of Asian and Indian population, immunity supported by VA, malnutrition, hunger, and health benefits of betalains and β-carotene. The search results shown by Web of Science, PubMed, Google Scholar, and Scopus database resulted in 492 articles, and of these, 89 articles were identified which focused either on food waste or vegetable waste management and only one article [29] focused on mitigating malnutrition and waste management related problems with well-established scientific approach as shown in Figure 1. However, this one article [29] did not focus on the type of food waste that could be targeted and the strategies to prevent malnutrition. Titles of all the studies were first read to determine their relevance to the topic. Full text of those found to be relevant (either on the basis of vegetable waste or malnutrition/VAD) were then read in full detail to determine eligibility for inclusion based on the above provided key words as inclusion criteria. Hence, to address this review gap, authors have selected 89 independent articles related to food waste or vegetable waste management and depleted health status and approaches taken to improve the health status in South Asian (SA) populations. As this is not a systematic review and meta-analysis, literature was reviewed as available and applicable information about the VAD, impaired immunity, and health benefits of betalains to mitigate several non-communicable diseases were reviewed. For this review, articles that were published after 2010 were included (Fig. 1).

Direct influence of VA and betalains on function of the immune system

Clinical trials, including those by Shankar, et al. [30], West, et al. [31], and Christian, et al. [32], showcased the varied impact of VA supplementation on health outcomes, particularly in reducing morbidity and improving immune response. In addition, Tang, et al. [23] and Qi, et al. [33] demonstrated the importance of VA in immune health, emphasizing its diverse dietary sources, through dietary interventions. Together, these studies underscore the multifaceted significance of VA in promoting overall health and immune function across different populations and interventions. While carotenoids have been linked to health benefits like reduced risk of certain diseases, it is the converted form, VA, that significantly affects the immune system [2]. Beetroot, once known for its vitamin C, iron, and folate content, is gaining attention for its immune-boosting potential, as it is attributed to the synthesis of

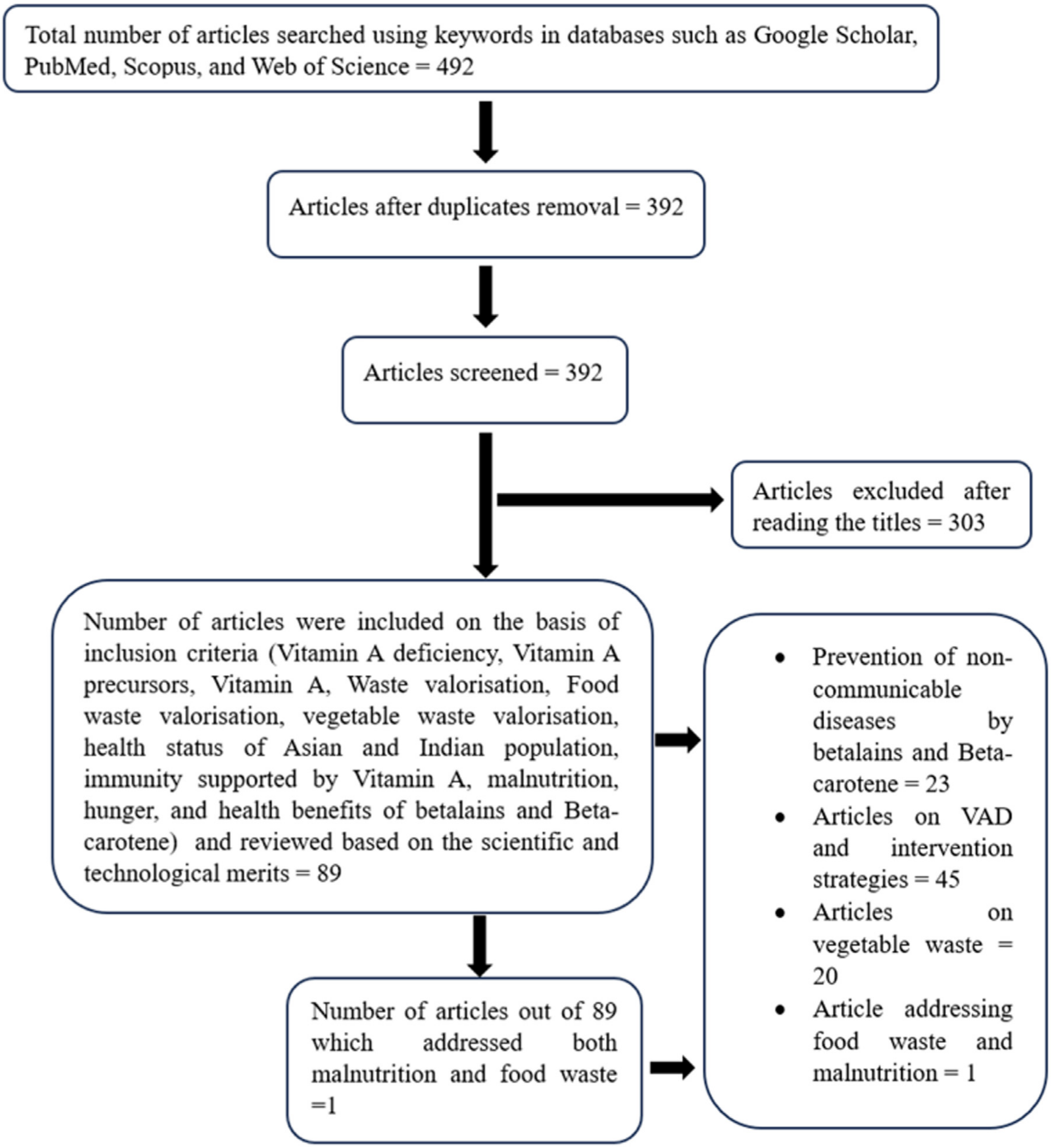

Fig. 1. Flowchart showing the steps involved in the selection of articles focusing on the relationship between food waste and malnutrition in South Asian population.

nitric oxide from betalains and nitrates in beetroot, and its role in immune regulation and anti-inflammatory effects [34]. Beetroot extract is considered a promising functional food for health promotion and disease prevention due to its various therapeutic properties, including oxidative stress reduction and immune system support [24,35].

VA deficiency: A South Asian perspective

VAD is a significant global health issue [36], affecting 120 to 170 million school-going children and 7 to 8 million pregnant women in developing and low-income South Asian countries. This deficiency leads to malnutrition, death, impaired health status, lower tissue development rate, slow metabolism, and vulnerability to infectious diseases [37–39].South Asian countries make up one-fifth of the global population and are severely affected by VAD [8]. Nearly 30% to 50% of preschool children in South Asia suffer from malnutrition and VAD, leading to the major cause of mortality in India and Bangladesh [40].

VAD is the most severe deficiency among other diseases in 1.02 billion people globally suffering from chronic malnutrition [7]. Studies have shown that 85% of children suffering from xerophthalmia reside in India [41,42]. The number of individuals suffering from VAD concerns health and safety points for the South Asian population. Immediate action through existing food regulations and new strategies to counter the deficiency on a mass scale is needed [14,43]. India has the highest proportion of VAD in preschool-going children among South Asian countries, at 62%, which is either clinical or subclinical as shown in Figure 1S. This substantial figure of deficiency leads to the death of 330,000 children annually in India alone and data for other South Asian countries is given in Table 1S. Subclinical VAD is also widespread in childbearing young mothers, with 5% suffering from night blindness during pregnancy. The highest proportion of pregnant women suffering from night-blindness are from rural areas [9,44,45].

VAD is a significant health issue in Pakistan, with diarrhea and pneumonia being major causes of child mortality. Measles-related VAD is prevalent among children under 6 y old, and the need for effective supplementation systems with high dose levels of VA is crucial. Nearly 53% of avoidable cases of child blindness were reported, with 58% preventable by meeting the daily requirement of VA in a blind and deaf school in Karachi city, Pakistan [12,13]. VAD is also prevalent among young people under 6 y of age in major regions of Pakistan. The prevalence of VAD among pregnant and non-pregnant women is a concern from a health perspective, but the sample size is small to accurately reflect the true extent of VAD in the region [46].

VAD is also recognized as a general health issue in Sri Lanka with 30% of the children of age less than 6 y are suffering from this deficiency [47], with a public overview led by the Medical Research Institute (MRI). A VAD control program was created to improve the VA status of preschool and elementary younger students, pregnant and lactating mothers. Food-based methods continued in Sri Lanka to control VAD, including dietary enhancement, development of VA-rich foods in home backyards, promotion of breastfeeding, and improving fat and VA-rich nourishments [8,14]. In Bangladesh, studies have revealed that 51% of pregnant women had a deficiency in the diet to meet the RDA for VA, and 18.5% showed VAD (serum retinol <0.70 μmol/L) [8,46]. Some of the factors such as diet and gestational age were shown to contribute to VAD in Bangladeshi women [48,49].

Considering all the data concerning VAD in South Asian countries, two factors were observed to be predominant; these include the early death of the new-borns or those aged less than 5 to 6 y, and blindness among the child-bearing women or girls. The epidemiological surveys have concluded that all the deaths and side effects of VAD were indirectly related to anemia, and reduced absorption of iron which ultimately leads to iron deficiency anemia and increased rate of mortality. Anemia is prevalent in non-industrial nations; about 42% of preschool children, 53% of young school-age children, 44% of women of childbearing age, and 56% of pregnant women are affected by anemia [50]. The reasons for anemia are different, yet among the main etiologies in non-industrial nations are iron insufficiency, intestinal sickness, some unavoidable illnesses, and poor health that ultimately affects hemoglobin, and VA level in human body. Insufficient intake of VA was recognized among the reasons for anemia [51,52], and it was attributed that VAD impacts anemia through regulation of hematopoiesis, by the improvement of insusceptibility to unavoidable illnesses [53,54].

The major factors for the prevalence of VAD in South Asian population are insufficient intake and poor absorption, which are impacted by socioeconomic status and socio-cultural limitations [8]. The conversion of β-carotene to VA, and storage in the body is shown in Figure 2 [55]. One of the predominant dietary factors is a low intake of animal-based foods (meat and dairy) which are good sources of fat-soluble vitamins such as A, D, E, and K. There are several vegetable sources of VA (please refer section “Direct fortification of food items to counter VAD in South Asia”), but the consumption needs to be in large volumes, or from a concentrated source, which is difficult to afford by the lower socioeconomic group, and difficult for young children to consume the volume of vegetables needed to meet their VA requirements [56].

Direct fortification of food items to counter VAD in South Asia

While VAD remains a significant public health concern in South Asia, various intervention programs have been implemented over time to address this issue. These programs target specific populations and utilize different strategies to combat VAD. Here are some of the current/past intervention programs in South Asian countries:

1. Fortification of vegetable vanaspati ghee: The India, Malaysia, and Pakistan in South Asia have initiated programs to fortify vegetable vanaspati ghee, aiming to increase the VA content in these widely used cooking fat/oils [57].
2. Fortification of vegetable oils with retinol: Fortifying commonly used vegetable oils with synthetic retinol (a form of VA) is another intervention strategy [58]. This approach helps enhance the nutritional content of cooking oils that are widely consumed in the region.
3. Fortification and Genetic Modification of Rice (Yellow Rice): Yellow rice, a genetically modified variety, has been introduced as part of fortification efforts [59]. This type of rice is enriched with β-carotene as a precursor of VA, addressing the deficiency in regions where rice is a staple food.
4. VA Supplementation as Retinol: Specific intervention programs focus on providing VA supplementation in the form of synthetic chemical retinol. This is particularly targeted at vulnerable populations, including young children (6–59 mo old) and pregnant girls and women [60].
5. Supplementation via Sugar and Flour: Some intervention programs involve the fortification of sugar and flour with VA. This ensures that these commonly consumed food staples contribute to the daily VA intake of the population [61].

The major target audiences for these intervention programs include:

- Young children (6–59 mo old): These programs aim to address VA deficiency in the early stages of life when nutritional support is crucial for growth and development [62].
- Pregnant girls and women: Recognizing the increased nutritional needs during pregnancy, intervention programs focus on providing VA supplementation to pregnant women [48], reducing the risk of deficiency-related complications.

By targeting these specific demographic groups and employing various strategies such as fortification and supplementation, South Asian countries aim to alleviate the burden of VAD and improve the overall health and well-being of their populations. Ongoing monitoring and assessments are essential to gauge the effectiveness of these intervention programs and make necessary adjustments as needed.

It is evident from the above information that fortification of other food products has been also practiced but failed. It could be attributed to the studying fortification at an ideal and controlled condition that is otherwise not possible in real life of a common person. For example, when yellow rice or any other fortified food products were given to the participants, they were supplemented with the required amount of butter/fat to help with the incorporation of the VA sources in the human body, which was otherwise not possible in real scenarios [59]. Hence, later many of the studies were focused on extraction and stability of β-carotene/VA products in various vegetables oils, which are also a major part of the diet by frying and cooking in South Asian countries [63]. Another reason for using sunflower/soybean oils in most of studies is the stability

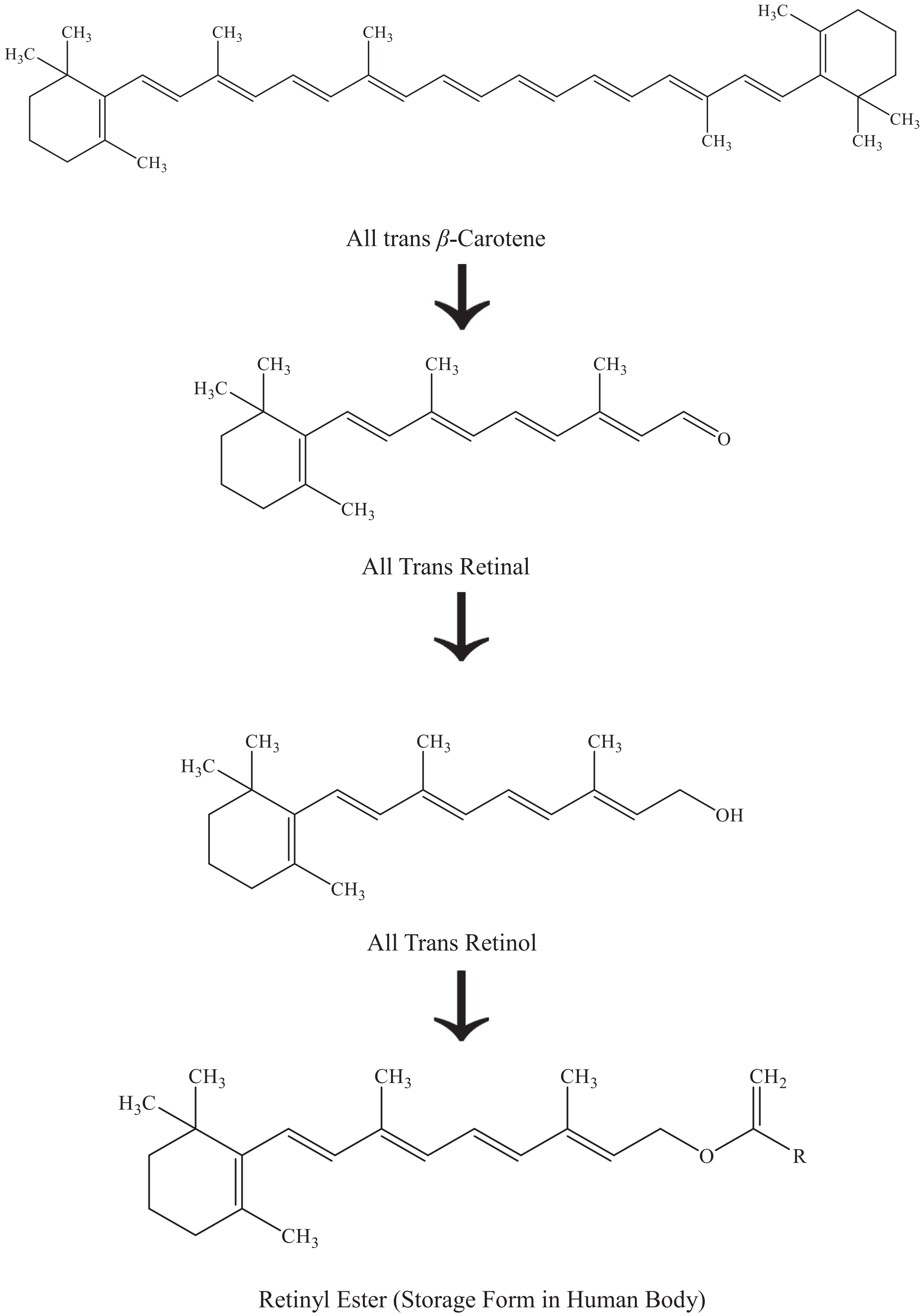

Fig. 2. Steps involved in the conversion of all-trans β-carotene to Retinyl ester (storage form in body). Retinoid is originally derived from proretinoid carotenoids such as β-carotene. Retinal can be formed by the central cleavage of β-carotene by the enzyme β-carotene 15,15′-monoxygenase. Retinol is formed by the reversible reduction of retinal by one of the retinal reductase family members. The enzyme lecithin retinol acyltransferase synthesizes retinyl esters by transferring a fatty acyl moiety from the sn-1 position of membrane phosphatidyl choline to retinol.

of β-carotene in these oils and higher bioavailability due to the higher degree of unsaturation of these oils [64].

To support the above hypothesis about the use of sunflower oil and ability to enhance the absorption of carotenoids, Linvy, et al. [65] reported that the inclusion of sunflower oil in meals significantly improved the absorption of β-carotene, particularly when consumed with cooked, pureed carrots compared to raw, chopped carrots. Sunflower oil played a crucial role in enhancing β-carotene bioavailability through several mechanisms. First, its fat content facilitated the solubility of β-carotene during digestion, making it more accessible for absorption. Additionally, sunflower oil promoted the formation of micelles, which served as carriers for fat-soluble β-carotene, aiding its transport across the intestinal lining. Furthermore, the presence of antioxidants in sunflower oil protected β-carotene from degradation during digestion, preserving its bioactivity. Moreover, sunflower oil may have contributed to a shorter lag phase in β-carotene absorption, optimizing transit time through the gastrointestinal tract. Overall, the study underscores the importance of sunflower oil in enhancing the bioavailability of β-carotene from vegetable sources, particularly when consumed in processed forms like cooked, pureed carrots. Hence, sunflower oil would be even more effective if it was consumed with extracted β-carotene.

Identification of the potential dietary bioresources to combat VAD and boosting health status

South Asian countries are rich in plant sources of PVA, such as carrots, amaranth, and leafy vegetables, which play a vital role in providing essential nutrients for health. Additionally, yellow vegetables like tomatoes, pumpkins, squash, and spinach serve as substantial sources of PVA as shown in Table 1.

In South Asian countries, the substantial production of vegetables is hampered by inadequate processing facilities, leading to a significant waste issue. This problem is particularly pronounced in Asian countries, where 35% to 55% of fresh produce is wasted due to factors like a lack of cold supply chains, storage, and proper handling [16,66,67]. In India, vegetable production in the fiscal year 2019−20 reached 189 million metric tons, representing a considerable portion of global vegetable production, the data for vegetable production by other South Asian countries are also given in Table 2S (a)−(d) [68]. Hence, this amount of waste not only squanders energy, water, labor, and resources involved in the entire value chain but also exacerbates issues like VAD and immune health in the South Asian community. Utilizing these discarded bioresources could provide an indigenous solution to these problems while also contributing to economic recovery and reducing the environmental impact associated with waste and global warming.

Food waste is a pressing global issue, with approximately one-third of the world's food production going to waste, a statistic that, if represented as a country, would rank it as the third-largest contributor to global warming, following China and the United States [69]. Various factors contribute to this problem, including household waste as shown in Table 3S, overproduction, inadequate storage and preservation facilities, the lack of cold supply chains, losses in the food processing industry and trade, post-harvest waste due to mechanical inefficiencies, and a lack of automation in handling and packaging [70]. This not only has significant economic implications but also poses a considerable threat to global warming. Importantly, the global warming potential (GWP) of imported vegetables is higher than domestically grown ones, largely due to long-distance transportation. Processing steps, such as packaging and on-farm production, each contribute 16% to the GWP, with processing itself accounting for 13% [28]. Canning, due to heavy machinery and heating requirements, is a major contributor to GWP in the packaging phase [71]. Furthermore, growing conditions, such as greenhouse cultivation, can require more energy than the imported produce. In terms of carbon footprint (CFP), cereals are the highest CFP producers quantitatively, followed by vegetables and then meat. Despite its lower volume, meat and animal product waste has the highest CFP per kilogram [69]. In India, an average of 7% of domestic vegetable supply goes to waste, an amount sufficient to meet the United Kingdom's needs [72]. This excessive waste generation not only challenges existing systems but also raises concerns about the associated environmental impact. Food waste contributes to various ecological problems, including climate change, eutrophication, acidification, ozone layer depletion, resource depletion, and biodiversity loss [73−75]. With global food demand projected to increase by 70% by 2050, addressing food waste is crucial for both food security and reducing unnecessary economic costs, all while considering the moral imperative, as millions of people around the world suffer from undernourishment [76].

Innovative fortification approaches and health benefits of β-carotene and betalains

In Kenya, Nderitu, et al. [77] studied the fortification of β-carotene in sunflower and palm oil to increase the β-carotene level. Similarly, Gurumeenakshi, et al. [78], Arumugam, et al. [79], and Borguini, et al. [58] fortified vegetable oil with β-carotene extracted from carrot (olive, soybean, sunflower, palm, and other

Table 1
Potential food commodities containing VA/β-carotene including plant and animal sources

S. no.	Food commodities	β-carotene	Amount of β-carotene found	References
1	Carrot	β-carotene	52−60 mg/100 g of dry carrot	[89]
2	Tomatoes	β-carotene	3.8−7.03 mg/100 g of dry tomato	[90]
3	Amaranth (red or green)	β-carotene	300.2 μg/g fresh	[91]
4	Spinach	β-carotene	6.29 mg/100 g fresh	[23]
5	Orange-fleshed sweet potatoes	β-carotene	11.5 mg/100 g fresh	[92]
6	Squashes/pumpkins	β-carotene	4.57 mg/100 g fresh	[93]
7	Yellow maize	β-carotene	0.38 mg/300 g cooked serving	[94]
8	Mangoes	β-carotene	0.55−3.21 mg/100 g	[95]
9	Papayas	β-carotene	2.14−2.74 mg/100 g of raw papaya	[96]
10	Liver	β-carotene	58.28−203 μg/g fresh	[4]
11	Eggs	β-carotene	5.19−200 mg/100 g of eggs	[97]
12	Milks (including breast milk)	β-carotene	1.45−3.60 μg/g of fat	[98]
13	Red palm oil	α and β-carotene	500 μg/g of palm oil	[99]

Table 2
List of studies that focused on fortification approaches

S. no.	Food bio-products used/source of VA used	Role of β-carotene as a fortificant/extract	Foods fortified	Trials/experiments conducted	Main findings	References
1.	*Solanum nigrum* and *Asystasia mysorensis*	β-carotene as precursor to VA	Sunflower and palm oils	Extraction of β-carotene in oils. Storage study of β-carotene in vegetable oils for 180 d.	β-carotene was fortified in sunflower and palm oils to address the antagonism of its use in food and application to elevate β-carotene levels.	[77]
2.	Fresh carrot	β-carotene as precursor to VA	Gingelly and mustard oils	Extraction, encapsulation, and fortification of oils with storage stability of 60 d.	Cold press extraction with hexane was the best solvent. Most suitable wall material for encapsulation was lecithin. β-carotene was stable in the mix.	[78]
3.	β-carotene	β-carotene for meeting daily requirements and extending the shelf-life of oil	Cold pressed virgin coconut oil	Shelf-life of oil and stability of β-carotene was assessed.	Produced oil was a suitable medium for producing value added functional oil.	[79]
4.	Dried carrot	Aimed to meet the recommended daily intake for VA	Soybean and olive oils	Enrichment of the oils with β-carotene and shelf-life study.	10 mL of soybean oil or olive oil supplied the Recommended Daily Intake for VA for an adult (equivalent to 600 µg retinol).	[58]
5.	Dried carrot	Extraction of β-carotene as a precursor for VA	Sunflower oil	Enrichment of the sunflower oil for better bioavailability of β-carotene and understanding the thermal stability as higher temperature.	β-carotene was efficiently extracted in shorter time compared to ultrasound and supercritical fluid extraction.	[100]
6.	VA (retinyl ester)	Meeting the daily requirements of VA after heating/ cooking/deep frying.	sunflower oil, soybean oil, corn oil and vegetable ghee	Heated different oil at temperature range of 100-175°C for 5–30 min and VA level was evaluated.	More than 60% of the VA was retained in the oils even after heating at 175°C. And this concentration which was enough to meet the daily requirements.	[81]
7.	Peach palm fruit by-products	Ultrasound-assisted extraction of total carotenoids obtained from dried peach palm by-products using sunflower oil as extraction solvent at mild temperatures to incorporate β-carotene.	Sunflower oil for enrichment	Ultrasonic-assisted extraction (UAE) was performed in a sonication cleaning bath with varying intensity, temperature, and extraction time.	Maximum extraction of total carotenoids was 163.47 mg/100 g of dried peel. The experimental values under optimal condition were consistent with the predicted values.	[101]
8.	Dry tomato waste	Enriching the vegetable oil and extending the shelf-life.	Extra virgin sunflower, unrefined corn, refined rapeseed, extra virgin olive, olive pomace, soybean, refined sunflower, Peanut, rice, and grape seed oil	Dried tomato waste samples (5 g) were subjected to each of the following extraction procedures: 1) ultrasound-assisted extraction in 100 mL oil at 20°C for 50 min; 2) microwave-assisted extraction in 100 mL oil for 5 min; 3) maceration at 20°C in 100 mL oil for 7 d.	Carotenoids were extracted in oils in significant amounts from tomato waste. Extraction of dry tomato waste improved the oxidative and thermal stability of oil and vice-versa.	[102]

vegetable oils). Nderitu, et al. [77] reported that after 6 mo of storage, mean levels of β-carotene were reduced significantly ($P < 0.001$) by over 65%, however the remaining concentration of β-carotene was still under the recommended level of RDA. On the other hand, Nderitu, et al. [77] and Gurumeenakshi et al. [78] reported that due to the fortification with β-carotene, the oil quality was reduced in terms of rancidity and peroxide values compared to the initial quality. In conclusion, it could be implied that β-carotene can be fortified in sunflower and palm oils to address the nutritional problem despite antagonism of its storage and degradation as shown in Table 2.

Dutra-de-Oliveira, et al. [80] and Akhtar, et al. [81] used the synthetic form of VA (retinyl palmitate) to fortify soybean oil and evaluated the bioavailability of β-carotene after heating at different temperatures and cooking conditions. Dutra-de-Oliveira, et al. [80] and Dutra-de-Oliveira, et al. [82] reported that after heating at 100°C, there was no deterioration of β-carotene, and, at higher temperature (170°C), β-carotene was available up to 65% of initial concentration. On the other hand, Akhtar et al. [81] observed that retinyl palmitate that was added to refined soybean oil was stable when fortified into recommended dose and cooking techniques at a given temperature. This study encourages fortification in soybean oil because this oil has a strong hold in the market of developing countries and is consumed for meeting the fat requirements as well. It was reported that the bioavailability of the retinyl palmitate was completely intact throughout normal cooking. However, conducting the heating for 20 min reduced the biological availability by 50% and was observed to be temperature sensitive. Despite the instability and sensitivity to the high temperature treatment, the biological availability of the fortified VA source is encouraging and the use of potential bioresources from natural vegetable waste could be even more promising.

The rising trends of using β-carotene and betalains to prevent and mitigate several non-communicable diseases are shown in Table 3. Similar to β-carotene, betalains are also important bioactive compounds, which are proven bioactives to mitigate

Table 3
List of studies focusing on the health benefits of beetroot

S. no.	Source of betalains/ beetroot	Aims	Food fortified/designed	Trials/experiments conducted	Notable findings	References
1.	Beetroot	To modulate hypertension in hypertensive participants	Beverage prepared with mix of carrot and beetroot	The study participants (n = 24) were given 250 ml of the beverage for 60 d before assessment.	Beverage influentially reduced the pulse rate, systolic and diastolic pressure, triglycerides, and LDL levels	[83]
2.	Beetroot powder	To control hypertension as well as hyperlipidemia.	500–1000 mg of powder was dissolved in water with cholesterol rich diet.	This dose was given for 60 d to 24 participants.	Beetroot powder lowered the lipid profile and hence it could be used for the prevention of hyperlipidemia.	[85]
3.	Alcoholic extract of beetroot (mostly betanin)	To assess the anticancer effects on human colorectal cancer.	Freeze dried beetroot extract	Two human colorectal cancer cell lines and normal epithelial cell line of same embryonic origin were treated with extract of beetroot.	The extract was able to induce apoptosis in the cancer and normal cells like anticancer drugs.	[84]
4.	Beetroot	To increase the vegetable consumption for better health and meet the requirements.	100 g of sample bread contained 40 g of white or red beetroot.	120 participants of different origin and age group.	The likeness of bread was not affected by addition of vegetables in the bread. Acceptability of vegetable enriched bread as good as normal bread.	[86]
5.	Study 1: Beetroot juice. Study 2: Beetroot powder	Study 1: To study the dose-dependent effects of beetroot juice in 18 healthy normotensive men. Study 2: to investigate the effects of red or white beetroot enriched bread products on blood pressure in 14 healthy men.	Study 1: Beetroot Juice. Study 2: Breads enriched with white and red beetroot.	Study 1: 18 participants sample 1 = 500 g water sample 2 = 100 g Juice + 400 g water sample 3 = 250 g Juice + 250 g water Sample 4 = 500 g juice. Study 2: 14 participants Sample 1 = 0 g Beetroot in 200 g bread. Sample 2 = 50% beetroot in 200 g bread.	Study 1: With increase in the beetroot juice consumption, there was significant reduction in SBP and DBP after 90 min of drinking. Study 2: Postprandial SBP and DBP started to decrease after 60 min of the consumption of breads incorporated with white or red beetroot.	[103]

hypertension, colorectal cancer, hyperlipidemia, and other non-communicable diseases [83–86]. Razzaq, et al. [83] studied the effect of carrot-beet–based beverages to modulate hypertension, where two kinds of beverage combinations were used (1) carrot juice 20% and beetroot juice 80% and 2) carrot juice 40% and beetroot juice 60%). The study demonstrated that betalains, present in both beverages, showed a positive influence on hypertension and can be considered for inclusion in dietary therapy to address this condition [83]. However, the specific mechanisms by which betalains affect blood pressure and lipid profiles may require further research for a more comprehensive understanding of their potential benefits. In the colorectal cancer cell lines study conducted by Saber et al., (2020) reported that betanin and the hydro-alcoholic extract of red beetroot demonstrated effectiveness in inhibiting the growth of colorectal cancer cells, inducing apoptosis in these cells, and did so with minimal harm to normal epithelial cells. The findings support the potential of betanin as a chemopreventive and anticancer agent, although further research is needed to fully understand the underlying mechanisms of its anticancer effects [84]. In another study, Sarfaraz, et al. [85] evaluated the effect of lyophilized beetroot powder at different doses for its hypolipidemic effects and showed that the presence of betalains in beetroot was found to have a positive impact on lipid profiles, suggesting that beetroot powder may be a beneficial dietary intervention for individuals with hyperlipidemia or those at risk of cardiovascular diseases. Hence, it could be concluded that beetroot is a nutritionally dense, natural food with a range of potential health benefits [86] and it might have a positive impact on cardiovascular health, hypertension, hyperlipidemia, and potentially even certain types of cancer.

Conclusion

In conclusion, the significance of harnessing the potential of bioactives like β-carotene and betalains from vegetables such as carrots and beetroots is undeniable, given their extensive health benefits and ready availability as potential bioresources in South Asian countries. Waste generation, stemming from farm to household, is intrinsically linked to fresh produce, highlighting the need for a more scientific approach in utilizing these resources efficiently. By extracting these valuable compounds, we not only address deficiencies like VAD which is highly prevalent in South Asian countries but also provide protection against various non-communicable diseases.

The development of sustainable solutions for managing byproducts can be done by food waste management. The nexus between food waste management, waste valorization, and addressing VAD is intricately tied to the principles of reduce, reuse, and recycle [87]. By strategically implementing these waste management practices, we can not only minimize the overall food waste footprint but also capitalize on the nutritional potential of discarded by-products. The reduction of food waste at the source is complemented by the reuse of specific by-products rich in PVA carotenoids, which may be traditionally discarded. Through innovative recycling processes, these by-products can be transformed into biofortified ingredients, contributing to the alleviation of VAD. This integrated approach underscores the potential for sustainable solutions that simultaneously enhance nutritional outcomes and minimize the environmental impact of food waste [88].

Hence, these solutions should tap into the inherent nutritional and functional value of biomaterials, yielding economic, social, and environmental advantages. In an era where nutritional problems and the ever-growing South Asian population pose serious challenges, repurposing food waste for human consumption should be a top priority. By leveraging the nutritional potential of waste and byproducts in South Asian countries, we not only enhance food security but also create opportunities for livelihoods, offering a compelling social benefit. In essence, the efficient use of bioresources and the reduction of food waste are essential components of a healthier, more sustainable future for our planet and its people.

While fortification of VA is a proven strategy to combat deficiency, challenges such as infrastructure, distribution, awareness, quality control, and economic factors can hinder successful implementation [61]. Addressing these limitations requires a multifaceted approach, involving collaboration across sectors, investment in capacity building, robust monitoring systems, community engagement, and adherence to quality standards. By systematically addressing these challenges, fortification programs can be more effective in improving micronutrient status and promoting public health.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Rahul Kumar: Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft. **Maria Jose Oruna-Concha:** Funding acquisition, Project administration, Supervision, Writing – review & editing. **Keshavan Niranjan:** Funding acquisition, Project administration, Supervision, Writing – review & editing. **Karani S. Vimaleswaran:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

Data availability

All data provided here in the manuscript.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2024.112452.

References

[1] Huang Z, Liu Y, Qi G, Brand D, Zheng S. Role of vitamin A in the immune system. J Clin Med 2018;7:258. https://doi.org/10.3390/jcm7090258.

[2] Clark S. Beta carotene. XPharm Compr Pharmacol Ref 2007:1–3. https://doi.org/10.1016/B978-008055232-3.61302-9.

[3] Almagro L, Correa-Sabater JM, Sabater-Jara AB, Pedreño MÁ. Biotechnological production of β-carotene using plant in vitro cultures. Planta 2022;256:1–9. https://doi.org/10.1007/s00425-022-03953-9.

[4] Strobel M, Tinz J, Biesalski HK. The importance of β-carotene as a source of vitamin A with special regard to pregnant and breastfeeding women. Eur J Nutr 2007;46:1–20. https://doi.org/10.1007/s00394-007-1001-z.

[5] Fragoso YD, Campos NS, Tenrreiro BF, Guillen FJ. Revisão sistemática da literatura sobre vitamina a e memória. Dement Neuropsychol 2012;6:219–22. https://doi.org/10.1590/S1980-57642012DN06040005.

[6] Imdad A, Mayo-Wilson E, Haykal MR, Regan A, Sidhu J, Smith A, et al. Vitamin A supplementation for preventing morbidity and mortality in children from six months to five years of age. Cochrane Database Syst Rev 2022;2022. https://doi.org/10.1002/14651858.CD008524.pub4.

[7] World Health Organization. The state of food security and nutrition in the world 2020: transforming food systems for affordable healthy diets, Vol. 2020. Food & Agriculture Org; 2020.

[8] Akhtar S, Ahmed A, Randhawa MA, Atukorala S, Arlappa N, Ismail T, et al. Prevalence of vitamin A deficiency in South Asia: causes, outcomes, and possible remedies. J Health Popul Nutr 2013;31:413–23. https://doi.org/10.3329/jhpn.v31i4.19975.

[9] Ministry of Health and Family Welfare. Government of India. National Family Health Survey (NFHS-5), key indicators. 2019:142.

[10] Sommer A, Djunaedi E, Loeden A, Tarwotjo I, West K, Tilden R, et al. Impact of vitamin a supplementation on childhood mortality. Lancet 1986;327:1169–73. https://doi.org/10.1016/s0140-6736(86)91157-8.

[11] United Nations Conference on Trade, Asian Development Bank. Food security in South Asia: developing regional supply chains for the food processing industry. 2015.

[12] Khan SJ, Hassan A, Khalid L, Karim U, Hashmi E, Gul F, et al. Blindness in children at the Ida Rieu School for the blind and deaf. J Pak Med Assoc 2007;57:334–7.

[13] Khan I, Baseer A. Hematologic effect of vitamin A supplementation in anemic Pakistani children. J Pak Med Assoc 1996;46:34–8.

[14] Nair H, Arya G, Vidnapathirana J, Tripathi S, Talukder SH, Srivastava V. Improving neonatal health in South-East Asia. Public Health 2012;126:223–6. https://doi.org/10.1016/j.puhe.2011.12.006.

[15] United Nations Environment Programme. Worldwide food waste. Dly Ft 2019:2–5.

[16] Porat R, Lichter A, Terry LA, Harker R, Buzby J. Postharvest losses of fruit and vegetables during retail and in consumers' homes: quantifications, causes, and means of prevention. Postharvest Biol Technol 2018;139:135–49. https://doi.org/10.1016/j.postharvbio.2017.11.019.

[17] West KP. Vitamin A: deficiency and interventions. Encycl Hum Nutr 2012;4–4:323–32. https://doi.org/10.1016/B978-0-12-375083-9.00274-9.

[18] Carrillo C, Nieto G, Martínez-Zamora L, Ros G, Kamiloglu S, Munekata PES, et al. Novel approaches for the recovery of natural pigments with potential health effects. J Agric Food Chem 2022;70:6864–83. https://doi.org/10.1021/acs.jafc.1c07208.

[19] Le Mouël C, Forslund A. How can we feed the world in 2050? A review of the responses from global scenario studies. Eur Rev Agric Econ 2017;44:541–91. https://doi.org/10.1093/erae/jbx006.

[20] Barioni L, Benton T, Kingdom U, Herrero M, Rica C, et al. Chapter 5: food security 2018:1–164

[21] United Nations Environment Programme. Food waste index report 2021. 2021.

[22] Strotmann C, Göbel C, Friedrich S, Kreyenschmidt J, Ritter G, Teitscheid P. A participatory approach to minimizing food waste in the food industry—a manual for managers. Sustain 2017;9(1), 66. https://doi.org/10.3390/su9010066.

[23] Tang G, Qin J, Dolnikowski GG, Russell RM, Grusak MA. Spinach or carrots can supply significant amounts of vitamin A as assessed by feeding with intrinsically deuterated vegetables. Am J Clin Nutr 2005;82:821–8. https://doi.org/10.1093/ajcn/82.4.821.

[24] Clifford T, Howatson G, West DJ, Stevenson EJ. The potential benefits of red beetroot supplementation in health and disease. Nutrients 2015;7:2801–22. https://doi.org/10.3390/nu7042801.

[25] O'Byrne SM, Blaner WS. Retinol and retinyl esters: biochemistry and physiology. J Lipid Res 2013;54:1731–43. https://doi.org/10.1194/jlr.R037648.

[26] Zamani H, de Joode MEJR, Hossein IJ, Henckens NFT, Guggeis MA, Berends JE, et al. The benefits and risks of beetroot juice consumption: a systematic review. Crit Rev Food Sci Nutr 2020;0:1–17. https://doi.org/10.1080/10408398.2020.1746629.

[27] Kandula N, Ahmed M, Dodani S, Gupta L, Hore P, Kanaya A, Gany F. Cardiovascular disease & cancer risk among South Asians: impact of sociocultural influences on lifestyle and behavior. J Immigr Minor Health 2019;21:15–25.

[28] Frankowska A, Jeswani HK, Azapagic A. Environmental impacts of vegetables consumption in the UK. Sci Total Environ 2019;682:80–105. https://doi.org/10.1016/j.scitotenv.2019.04.424.

[29] Torres-León C, Ramírez-Guzman N, Londoño-Hernandez L, Martinez-Medina GA, Díaz-Herrera R, Navarro-Macias V, et al. Food waste and byproducts: an opportunity to minimize malnutrition and hunger in developing countries. Front Sustain Food Syst 2018;2:1–17. https://doi.org/10.3389/fsufs.2018.00052.

[30] Shankar AH, Genton B, Semba RD, Baisor M, Paino J, Tamja S, et al. Effect of vitamin A supplementation on morbidity due to. Lancet 1999;354:203–9.

[31] West Katz J, Leclerq SC, Pradhan EK, Tielsch JM, Sommer A, Pandey MR. Efficacy of vitamin A in reducing preschool child mortality in Nepal. The Lancet 1991;338(8759):67–71.

[32] Christian P, West KP, Khatry SK, Katz J, Leclerq SC, Kimbrough-Pradhan E, et al. Vitamin A or β-Carotene supplementation reduces symptoms of illness

in pregnant and lactating Nepali women. J Nutr 2000;130:2675–82. https://doi.org/10.1093/jn/130.11.2675.
[33] Qi YJ, Niu QL, Zhu XL, Zhao XZ, Yang WW, Wang XJ. Relationship between deficiencies in vitamin A and E and occurrence of infectious diseases among children. Eur Rev Med Pharmacol Sci 2016;20:5009–12.
[34] Kaur G, Thawkar B, Dubey S, Jadhav P. Pharmacological potentials of betalains. J Complement Integr Med 2018;15. https://doi.org/10.1515/jcim-2017-0063.
[35] Stanaway L, Rutherfurd-Markwick K, Page R, Ali A. Performance and health benefits of dietary nitrate supplementation in older adults: a systematic review. Nutrients 2017;9, 1171. https://doi.org/10.3390/nu9111171.
[36] Souganidis E, Laillou A, Leyvraz M, Moench-Pfanner R. A comparison of retinyl palmitate and red palm oil β-carotene as strategies to address vitamin A deficiency. Nutrients 2013;5:3257–71. https://doi.org/10.3390/nu5083257.
[37] Humphrey JH, Agoestina T, Wu L, Usman A, Nurachim M, Subardja D, et al. Impact of neonatal vitamin A supplementation on infant morbidity and mortality. J Pediatr 1996;128:489–96. https://doi.org/10.1016/S0022-3476(96)70359-1.
[38] Sommer A. Vitamin A deficiency and clinical disease: an historical overview. J Nutr 2008;138:1835–9. https://doi.org/10.1093/jn/138.10.1835.
[39] West K P Jr.. Extent of vitamin A deficiency among preschool children and women of reproductive age. J Nutr 2002;132:2857S–66S.
[40] World Health Organization. Global prevalence of vitamin A deficiency in populations at risk 1995-2005: WHO global database on vitamin A deficiency. WHO Iris; 2009. p. 55.
[41] Bastos Maia S, Costa Caminha MF, Lins da Silva S, Rolland Souza AS, Carvalho dos Santos C, Batista Filho M. The prevalence of vitamin A deficiency and associated factors in pregnant women receiving prenatal care at a reference maternity hospital in Northeastern Brazil. Nutrients 2018;10:1–14. https://doi.org/10.3390/nu10091271.
[42] FAO. World Declaration and Plan of Action for Nutrition. Int Conf Nutr 1992:1–42.
[43] Bhutta Z. Pakistan National Nutrition Survey 2011. National Nutrition Survey; 2012:1–84.
[44] Mayo-Wilson E, Imdad A, Herzer K, Yakoob MY, Bhutta ZA. Vitamin A supplements for preventing mortality, illness, and blindness in children aged under 5: systematic review and meta-analysis. BMJ 2011;343:1–19. https://doi.org/10.1136/bmj.d5094.
[45] Aguayo VM, Baker SK. Vitamin A deficiency and child survival in sub-Saharan Africa: a reappraisal of challenges and opportunities. Food Nutr Bull 2005;26:348–55. https://doi.org/10.1177/156482650502600404.
[46] Marjan N, Rahman A, Rois R, Rahman A. Factors associated with coverage of vitamin a supplementation among Bangladeshi children: mixed modelling approach. BMC Public Health 2021;21:1–11. https://doi.org/10.1186/s12889-021-10735-7.
[47] Liyanage G, Anupama KGIS, Sudarshini MLP. Acceptability of home fortification with multiple micro-nutrients among Sri Lankan children. PLoS One 2021;16:1–11. https://doi.org/10.1371/journal.pone.0261516.
[48] Ahmed T, Mahfuz M, Ireen S, Shamsir Ahmed AM, Rahman S, Munirul Islam M, et al. Nutrition of children and women in Bangladesh: trends and directions for the future. J Heal Popul Nutr 2012;30:1–11. https://doi.org/10.3329/jhpn.v30i1.11268.
[49] Lee V, Ahmed F, Wada S, Ahmed T, Ahmed AS, Parvin Banu C, et al. Extent of vitamin a deficiency among rural pregnant women in Bangladesh. Public Health Nutr 2008;11:1326–31. https://doi.org/10.1017/S1368980008002723.
[50] Sommer A, Vyas KS. A global clinical view on vitamin A and carotenoids. Am J Clin Nutr 2012;96:1204–6. https://doi.org/10.3945/ajcn.112.034868.
[51] Nguyen CK, Nguyen XN, Nguyen VN, Ha HK, West CE, Hautvast JGAJ. Sub clinical vitamin A deficiency and anemia among Vietnamese children less than five years of age. Asia Pac J Clin Nutr 2007;16:152–7.
[52] Khor GL. Micronutrient status and intervention programs in Malaysia. Food Nutr Bull 2005;26, S281-S285. https://doi.org/10.1177/15648265050262s220.
[53] Semba RD, Muhilal MPH, West KP, Winget M, Natadisastra G, Scott A, et al. Impact of vitamin a supplementation on hematological indicators of iron metabolism and protein status in children. Nutr Res 1992;12:469–78. https://doi.org/10.1016/S0271-5317(05)80017-X.
[54] Semba RD, Bloem MW. The anemia of vitamin a deficiency: epidemiology and pathogenesis. Eur J Clin Nutr 2002;56:271–81. https://doi.org/10.1038/sj.ejcn.1601320.
[55] Desobry SA, Netto FM, Labuza TP. Preservation of β-carotene from carrots. Crit Rev Food Sci Nutr 1998;38:381–96. https://doi.org/10.1080/10408699891274255.
[56] Augusto RA, Cobayashi F, Cardoso MA. Associations between low consumption of fruits and vegetables and nutritional deficiencies in Brazilian schoolchildren. Public Health Nutr 2015;18:927–35. https://doi.org/10.1017/S1368980014001244.
[57] Vir SC, Pandey RS, Vir SC, Pandey RS. Vitamin A prevention and control programme in India—past efforts and current status. Woodhead Publishing Limited; 2011. https://doi.org/10.1533/9780857093905.473.
[58] Borguini RG, Pacheco S, Chávez DWH, Couto GA, Wilhelm AE, de Araujo Santiago MCP, et al. Carotenoid extraction using edible vegetable oil: an enriched provitamin A product. Sci Agric 2020;78:1–11. https://doi.org/10.1590/1678-992x-2019-0332.
[59] Wu F, Wesseler J, Zilberman D, Russell RM, Chen C, Dubock AC. Allow golden rice to save lives. Proc Natl Acad Sci U S A 2021;118:15–7. https://doi.org/10.1073/pnas.2120901118.
[60] Sommerburg O, De Spirt S, Mattern A, Joachim C, Langhans CD, Nesaretnam K, et al. Supplementation with red palm oil increases β-carotene and vitamin A blood levels in patients with cystic fibrosis. Mediat Inflamm 2015;2015. https://doi.org/10.1155/2015/817127.
[61] Dwyer JT, Wiemer KL, Dary O, Keen CL, King JC, Miller KB, et al. Fortification and health: challenges and opportunities. Adv Nutr 2015;6:124–31. https://doi.org/10.3945/an.114.007443.
[62] Aguayo VM, Bhattacharjee S, Bhawani L, Badgaiyan N. India's vitamin A supplementation programme is reaching the most vulnerable districts but not all vulnerable children. New evidence from the seven states with the highest burden of mortality among under-5s. Public Health Nutr 2015;18:42–9. https://doi.org/10.1017/S136898001300342X.
[63] Bhardwaj S, Passi SJ, Misra A, Pant KK, Anwar K, Pandey RM, et al. Effect of heating/reheating of fats/oils, as used by Asian Indians, on trans fatty acid formation. Food Chem 2016;212:663–70. https://doi.org/10.1016/j.foodchem.2016.06.021.
[64] Gizir AM, Turker N, Artuvan E. Pressurized acidified water extraction of black carrot [Daucus carota ssp. sativus var. atrorubens Alef.] anthocyanins. Eur Food Res Technol 2008;226:363–70. https://doi.org/10.1007/s00217-006-0546-z.
[65] Livny O, Reifen R, Levy I, Madar Z, Faulks R, Southon S, et al. B-carotene bioavailability from differently processed carrot meals in human ileostomy volunteers. Eur J Nutr 2003;42:338–45. https://doi.org/10.1007/s00394-003-0430-6.
[66] Raut RD, Gardas BB, Narwane VS, Narkhede BE. Improvement in the food losses in fruits and vegetable supply chain - a perspective of cold third-party logistics approach. Oper Res Perspect 2019;6:100117. https://doi.org/10.1016/j.orp.2019.100117.
[67] Rahiel HA, Zenebe AK, Leake GW, Gebremedhin BW. Assessment of production potential and post-harvest losses of fruits and vegetables in northern region of Ethiopia. Agric Food Secur 2018;7:1–13. https://doi.org/10.1186/s40066-018-0181-5.
[68] Narayanamoorthy A, Bhattarai M, Jothi P. An assessment of the economic impact of drip irrigation in vegetable production in India. Agric Econ Res Rev 2018;31:105. https://doi.org/10.5958/0974-0279.2018.00010.1.
[69] Food and Agriculture Organization. (2015). Food wastage footprint & climate change.
[70] Iordachescu G, Ploscutanu G, Pricop EM, Baston O, Barna O. Postharvest losses in transportation and storage for fresh fruits and vegetables sector. J Int Sci Publ 2019;7:244–51.
[71] Etzel MR, Willmore P, Ingham BH. Heat penetration and thermocouple location in home canning. Food Sci Nutr 2015;3:25–31. https://doi.org/10.1002/fsn3.185.
[72] Sahu PK. Statistical analysis of vegetable production in India, China, and the World. J Veg Crop Prod 2004;10:3–9. https://doi.org/10.1300/J068v10n01_02.
[73] Garnett T. Fruit and Vegetables & UK Greenhouse Gas Emissions: exploring the relationship working paper produced as part of the work of the food climate. Food Clim Res Netw 2006:1–134.
[74] Majeau-Bettez G, Strømman AH, Hertwich EG. Evaluation of process- and input-output-based life cycle inventory data with regard to truncation and aggregation issues. Environ Sci Technol 2011;45:10170–7. https://doi.org/10.1021/es201308x.
[75] Pretty J, Sutherland WJ, Ashby J, Auburn J, Baulcombe D, Bell M, et al. The top 100 questions of importance to the future of global agriculture. Int J Agric Sustain 2010;8:219–36. https://doi.org/10.3763/ijas.2010.0534.
[76] FAO. Scialabba, N. (2015). Food wastage footprint & climate change. UN FAO, 15-19.
[77] Nderitu SM, Nawiri MP, Nyambaka HN. Fortification of sunflower and palm oils using beta carotene extracted from. Food Res 2018;2:437–42.
[78] Gurumeenakshi G, Varadharaju N, Malathi D, Subbulakshmi B, Rajeswari R. Fortification of carotene from carrots in cooking oil. Int J Curr Microbiol Appl Sci 2019;8:2547–54. https://doi.org/10.20546/ijcmas.2019.808.296.
[79] Arumugam M, Raman M, Eagappan K. Formulation and storage stability of beta carotene enriched vitamin d3 and omega 3 fortified cold pressed virgin coconut oil. Int J Pharm Pharm Sci 2014;6:112–6.
[80] Dutra-de-Oliveira JE, Leonardo IR, Jordão AA, Vannucchi H, Duarte Fávaro RM. Absorption, by Humans, of β-carotene from fortified soybean oil added to rice: effect of heat treatment. J Am Coll Nutr 1998;17:361–5. https://doi.org/10.1080/07315724.1998.10718776.
[81] Akhtar H, Tahir L, Mahmud S, Hamid S. Loss of vitamin A in fortified edible oils and ghee during cooking in Asian traditional style. Bangladesh J Sci Ind Res 2012;47:243–8. https://doi.org/10.3329/bjsir.v47i2.11461.
[82] Dutra-de-Oliveira J E, Duarte Fávaro, Leonardo I R, Jordão, Vannucchi H. Absorption, by humans, of β-carotene from fortified soybean oil added to rice: Effect of heat treatment. J Am Coll Nutr 1998;17(4):361–5.
[83] Razzaq P A, Butt M S, Haq I U, Tariq U. Effect of Carrot-Beet Based Beverages to Modulate Hypertension. UCP J Sci Technol 2023;1(1).

[84] Saber A, Abedimanesh N, Somi M-H, Khosroushahi AY. Anticancer effects of beetroot hydro-alcoholic extract and betanin on human colorectal cancer cell lines. Res Sq 2020;23(1):1–19.
[85] Sarfaraz S, Ikram R, Munawwar R, Osama M, Gul S, Sufian M. Rising trend of nutraceuticals: evaluation of lyophilized beetroot powder at different doses for its hypolipidemic effects. Pak J Pharm Sci 2021;34:1315–22. https://doi.org/10.36721/PJPS.2021.34.4.REG.1315-1322.1.
[86] Hobbs DA, Ashouri A, George TW, Lovegrove JA, Methven L. The consumer acceptance of novel vegetable-enriched bread products as a potential vehicle to increase vegetable consumption. Food Res Int 2014;58:15–22. https://doi.org/10.1016/j.foodres.2014.01.038.
[87] Pinotti L, Manoni M, Fumagalli F, Rovere N, Luciano A, Ottoboni M, et al. Reduce, reuse, recycle for food waste: a second life for fresh-cut leafy salad crops in animal diets. Animals 2020;10:1–14. https://doi.org/10.3390/ani10061082.
[88] Mahawar MK, Jalgaonkar K, Bibwe B, Bhushan B, Meena VS, Sonkar RK. Post-harvest processing and valorization of Kinnow mandarin (Citrus reticulate L.): a review. J Food Sci Technol 2020;57:799–815. https://doi.org/10.1007/s13197-019-04083-z.
[89] Gul K, Tak A, Singh AK, Singh P, Yousuf B, Wani AA. Chemistry, encapsulation, and health benefits of β-carotene—a review. Cogent Food Agric 2015;1, 1018696. https://doi.org/10.1080/23311932.2015.1018696.
[90] Toor RK, Savage GP. Antioxidant activity in different fractions of tomatoes. Food Res Int 2005;38:487–94. https://doi.org/10.1016/j.foodres.2004.10.016.
[91] Pritwani R, Mathur P. β-carotene content of some commonly consumed vegetables and fruits available in Delhi, India. J Nutr Food Sci 2017;7(5), 1-7. https://doi.org/10.4172/2155-9600.1000625.
[92] de Andrade Lima M, Kestekoglou I, Charalampopoulos D, Chatzifragkou A. Supercritical fluid extraction of carotenoids from vegetable waste matrices. Molecules 2019;24(3):466. https://doi.org/10.3390/molecules24030466.
[93] Chandra S, Khan S, Avula B, Lata H, Yang MH, ElSohly MA, et al. Assessment of total phenolic and flavonoid content, antioxidant properties, and yield of aeroponically and conventionally grown leafy vegetables and fruit crops: a comparative study. Evid Based Complement Altern Med 2014;2014:1–9. https://doi.org/10.1155/2014/253875.
[94] Muzhingi T, Gadaga T H, Siwela A H, Grusak M A, Russell R M, Tang G. Yellow maize with high β-carotene is an effective source of vitamin A in healthy Zimbabwean men. Am J Clin Nutr 2011;94(2):510–9.
[95] Rezaei M, Liu B. Food loss and waste in the food supply chain. Reus, Spain: International Nut and Dried Fruit Council; 2017. p. 26–7.
[96] Schweiggert RM, Kopec RE, Villalobos-Gutierrez MG, Högel J, Quesada S, Esquivel P, et al. Carotenoids are more bioavailable from papaya than from tomato and carrot in humans: a randomised cross-over study. Br J Nutr 2014;111:490–8. https://doi.org/10.1017/S0007114513002596.
[97] Volk SP. Impact of high-pressure processing on soy and egg proteins 2009:117.
[98] Ramalho HMM, Santos J, Casal S, Alves MR, Oliveira MBPP. Fat-soluble vitamin (A, D, E, and β-carotene) contents from a Portuguese autochthonous cow breed-Minhota. J Dairy Sci 2012;95:5476–84. https://doi.org/10.3168/jds.2010-3975.
[99] Dong S, Xia H, Wang F, Sun G. The effect of red palm oil on vitamin a deficiency: a meta-analysis of randomized controlled trials. Nutrients 2017;9(2), 1281. https://doi.org/10.3390/nu9121281.
[100] Kumar R, Oruna-Concha MJ, Balagiannis DP, Niranjan K. Elevated temperature extraction of β-carotene from freeze-dried carrot powder into sunflower oil: Extraction kinetics and thermal stability. J Food Sci 2024;89(3):1–16. https://doi.org/10.1111/1750-3841.16964.
[101] Ordóñez-Santos LE, Pinzón-Zarate LX, González-Salcedo LO. Optimization of ultrasonic-assisted extraction of total carotenoids from peach palm fruit (Bactris gasipaes) by-products with sunflower oil using response surface methodology. Ultrason Sonochem 2015;27:560–6. https://doi.org/10.1016/j.ultsonch.2015.04.010.
[102] Nour V, Corbu AR, Rotaru P, Karageorgou I, Lalas S. Effect of carotenoids, extracted from dry tomato waste, on the stability and characteristics of various vegetable oils. Grasas Aceites 2018;69(1), e238-e238. https://doi.org/10.3989/gya.0994171.
[103] Hobbs DA, Kaffa N, George TW, Methven L, Lovegrove JA. Blood pressure-lowering effects of beetroot juice and novel beetroot-enriched bread products in normotensive male subjects. Br J Nutr 2012;108:2066–74. https://doi.org/10.1017/S0007114512000190.