***HarvestPlus* biofortified crops could improve micronutrient supply in Papua New Guinea**

by Graham Lyons, University of Adelaide January 2019

**ABSTRACT**

Micronutrient deficiencies (MND), especially iron (Fe), vitamin A, zinc (Zn) and iodine (I), afflict more than two billion people globally. Biofortification is a promising, cost-effective and sustainable method to deliver micronutrients to a population that has limited access to diverse diets. This study examined agriculture, rice imports, human nutrition, health and disease patterns in Papua New Guinea (PNG), in order to identify the potential for *HarvestPlus* biofortified crops to alleviate important MND. Subsistence agriculture is the most important activity in PNG, and sweetpotato is easily the most important food crop. Protein malnutrition, sometimes accompanied by energy deficiency, and usually accompanied by deficiencies of vitamin A, Fe and Zn, is prevalent. These deficiencies contribute to high rates of infant and maternal morbidity and mortality, along with stunting. In rural areas, infectious diseases account for most illness and death. It is estimated that 42,000, 33,600 and 25,200 disability adjusted life years (DALYs, a measure of combined morbidity and mortality) are lost due to deficiencies of vitamin A, Fe and Zn, respectively, for a total of 101,000 DALYs lost; hence it is worthwhile to alleviate all of these deficiencies. On the other hand, diabetes, heart disease and certain cancers, caused largely by overconsumption of refined carbohydrates combined with underexercise, predominate in urban and peri-urban areas. These so-called *non-communicable diseases* (NCD) have increased in the last 30 years to become important contributors to national morbidity and mortality statistics. It is considered that the following HarvestPlus biofortified crops could reduce MND in PNG: orange sweetpotato (OSP), orange maize, Zn-rice and Fe-beans. Because of the importance of sweetpotato in PNG, along with the high b-carotene content of OSP, it has the greatest potential to alleviate a micronutrient deficiency, i.e. vitamin A. Nevertheless, maize is also grown by most farmers and new, high-yielding varieties are needed. Most rice is imported and Zn-rice would need to be priced competitively to be attractive to importers. Fe-beans would need to contain higher Fe than popular PNG peanuts and beans. It is recommended that these biofortified crops be trialled initially alongside the best local varieties in both highland and lowland environments. Iodine deficiency remains common in PNG, due largely to lack of enforcement of universal salt iodization. This needs to be addressed as part of this food system strategy to improve human health in PNG.

**AIMS**

1. To explore the literature and contact key organizations and personnel, in order to
2. provide a current view of agriculture, human nutrition and health in PNG, and
3. identify the main MND that impact on human health in PNG.
4. To discuss the potential of the following HarvestPlus biofortified crops to alleviate deficiencies of vitamin A, Zn and Fe in PNG: orange sweetpotato (OSP), orange maize, Zn-rice, and Fe-beans.

**METHODS**

Searches of the following databases: PubMed, CAB Abstracts, Scopus, BIOSIS, Web of Science Core Collection, Agricola, AGRIS (FAO), FSTA, Embase, in addition to Google searches of the internet, with search terms (in various combinations) micronutrient, deficiency/ies, Papua New Guinea, food production, health, diseases, then more specific searches: biofortified/biofortification, vitamin A, iron, zinc with/without deficiency/ies; maize, rice, sweetpotato (and sweet potato), beans, legumes, pulses. Also searched relevant websites, including the National Department of Health and the Department of Agriculture and Livestock, HarvestPlus, CIP, IITA, CIMMYT.

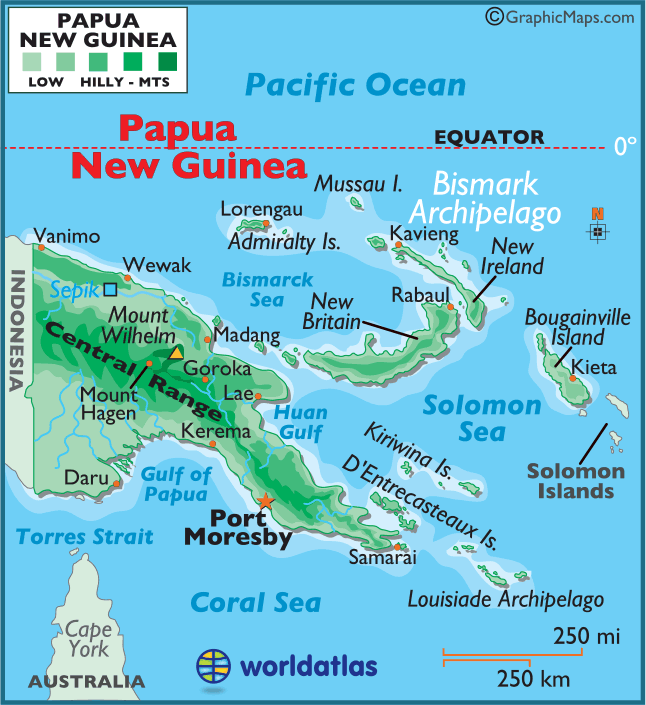
Contacted the PNG National Agricultural Research Institute (NARI) at Bubia, Lae; HarvestPlus (Dr Wolfgang Pfeiffer), International Potato Center (CIP), International Institute of Tropical Agriculture (IITA), Professor Peter Heywood, Professor Chris Blanchard, Dr Ehsan Tavakkoli and Rachael Wood (Charles Sturt University, Wagga Wagga, NSW), David Troldahl (New South Wales Department of Primary Industries, Yanco), Dr Tim Gill (DFAT) and Dr R Michael Bourke (Australian National University, Canberra). Mike Bourke is the doyen of PNG agriculture, with a research, advisory and commentary record back to the early 1970s, and has authored/co-authored most of the definitive publications in agriculture, population and health in PNG over recent decades. He was particularly helpful with this study, providing key insights and references, including his comprehensive database, containing i.a.“grey literature” which is otherwise not readily available, and I am grateful for his input.

In order to obtain more data on standard/baseline levels of Zn in rice currently consumed in PNG, I bought seven samples of brown and polished rice, sourced from Australia, Vietnam, Thailand and Pakistan from Coles supermarket at Burnside, Adelaide and had them analyzed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Glen Osmond, using inductively coupled plasma optical emission spectrometry (ICP-OES).

**INTRODUCTION**

***Background***

Papua New Guinea (PNG) includes the eastern half of the island of New Guinea (the western half is Papua, part of Indonesia), the islands of New Britain, New Ireland , Bougainville and hundreds of smaller islands (Figure 1). Land area is 463,000 km2, of which only 27% is occupied by people. It is usually divided into the islands, lowlands (0-1200 m) and highlands (1200-2800 m). Current population is estimated at 8.4 million and the fertility rate (children per woman) and population growth rate (% increase per annum) are relatively high, at 4.0 and 2.1, respectively. About 77% of people live in rural areas, and about 40% of the rural population live in the highlands. PNG is thought to have been occupied by humans for at least 40,000 years, and there are over 800 distinctive local cultures and languages (Hanson et al, 2001; Bourke and Allen, 2009; [www.healthdata.org](http://www.healthdata.org) ).



**Figure 1.** Papua New Guinea

Customary land accounts for c 97% of the total land area (i.e. no title deeds). This form of tenure is often cited by Western economists as an impediment to progress, but this is not necessarily correct. Individual titles to land on settlement schemes have often resulted in poor economic outcomes. Only where uncertainties in tenure are causing real problems, such as in the peri-urban areas of the larger towns, should attempts be made to interfere with customary tenure (Hanson et al, 2001; Bourke and Allen, 2009).

Most rain falls between January and April in many parts of PNG, with least from May to August. But in some areas this is reversed and in some other areas it rains all year with no seasonal pattern. This reminds me of a tourism poster in my Port Moresby hotel room in 2010, which proclaimed *Papua New Guinea: Land of the unexpected!* The El Nino Southern Oscillation (ENSO) can sometimes cause periods of unusually low rainfall, and around every 30 years these will be severe enough to greatly reduce food production (Allen and Bourke, 2009).

***Agriculture***

Agriculture is the most important activity carried out by the vast majority of Papua New Guineans. It fills their lives physically, culturally, economically, socially and nutritionally. Yet agriculture is the most undervalued and misunderstood part of PNG life. Subsistence food production is the most important part of PNG agriculture (Bourke and Allen, 2009).

Soils are relatively young; the most common being *Inceptisols* (moderately weathered soils) and *Andisols* (volcanic ash soils), then *Entisols* (very young soils). Soil nutrient deficiencies (including P, N, K, B, Zn, etc) are common in parts of PNG and increase under intensification of land use, which tends to shorten fallow time (van Wijmeersch, 2001; Allen and Bourke, 2009). An ACIAR study found that K was the most limiting nutrient, affecting a third of sweetpotato (SP) gardens, and was more severe in old gardens. Phosphorus deficiency was important on volcanic soils and S on non-volcanic soils. Removal of vines contributed to lower K and S (Bailey, 2009). If intensification is not accompanied by suitable land management practices, agricultural pressure on land will lead to land degradation and reduced crop yields. “High value” compost materials such as lupins and Mexican sunflower in SP mounds can increase SP yield (Kapal et al, 2010), but eventually mineral fertilizers will be needed (Fujinuma et al, 2018).

Environmental factors other than soil fertility that constrain agriculture in PNG include very high rainfall, steep slopes, frost, drought, inundated land, extensive cloud cover, disease epidemics and clan fights (Hide et al, 1992; Bank and Kanua, 2001; Bourke, 2001; Hanson et al, 2001; van Wijmeersch, 2001; Bourke and Vlassak, 2004; Bourke et al, 2009). The concept of “land quality”, defined as the ability of the land to grow particular crops at their optimum production over a long period, can be applied to any country. In PNG, only 25% of total land area is used for agriculture, and about 70% of this is of low/very low quality, in terms of SP production. Most of the rural population occupies land of moderate/low quality (Allen and Bourke, 2009).

Nonetheless, current food security is generally good in PNG. This is because a high proportion of the population is engaged in food production, most people have access to land and they rely on a diverse range of subsistence food sources. In most parts of PNG, villagers have increased production as population has grown to maintain adequate food. Rice and wheat are the most important imported foods; since 1998 wheat imports per person have been increasing while rice imports have remained static (Hanson et al, 2001; Bourke et al, 2009; M Bourke pers comm, 2018).

The staple foods are mainly starchy root crops, sago and banana. Staples grown by smallholders are important to the PNG economy, though most are produced and consumed by the same household (Bourke and Vlassak, 2004). Sweetpotato dominates food production in PNG (especially in the highlands), accounting for 64% of production of staple food crops by weight and 63% of food energy production. No other staple in PNG contributes more than 10% by weight or food energy. There are no other crops that can be readily substituted for SP in the highlands, where it has been cultivated for c 350 years, unlike in most lowland locations. Nevertheless, it is likely to become the dominant lowland crop by c 2030. It is grown in almost every agricultural system in PNG. At higher altitude it is grown for 6-8 months to main harvest, but just 3-5 months in the lowlands. Cassava is important in the lowlands, taro is grown in most locations, but often only as a supplementary crop, while yam is an important staple in some locations (Hanson et al, 2001; Bourke and Vlassak, 2004; Bourke and Allen, 2009; Schmidt et al, 2018).

Papua New Guinea is regarded as the second-largest centre of SP genetic diversity in the world, with the number of varieties grown estimated at c 5,000, and indigenous knowledge of the crop is profound. In a highlands survey, the number of varieties grown by various groups of villagers was 6-71, with a mean of 33. About 50% of highlands SP production is fed to pigs, typically the smaller tubers considered unsuitable for human consumption. As agricultural intensity increases (especially since 1970), so has the tendency for SP to become the most important crop. The past 55 years has seen the increased significance of New World crops, i.e. SP, cassava, potato, Chinese taro, while crops of Asia-Pacific origin, i.e. banana, sago, taro, yam have mostly declined (Sowei et al, 1992; van Wijmeersch, 2001; Bourke and Vlassak, 2004; M Bourke, pers comm, 2018).

Sweetpotato, maize, rice and beans will be discussed in more detail below, under *Opportunities for* HarvestPlus *biofortified crops to reduce MND in PNG.*

In addition to the high-carbohydrate crops above, many species of leafy green vegetables are eaten in PNG, and consumed daily. The most important greens are pumpkin and choko tips, *aibika*, amaranthus, *rungia* , *tulip*, *oenanthe*, cabbage, fern fronds, *rorippa* and taro leaves (Bourke et al, 2009). Projects funded by the Australian Centre for International Agricultural Research (ACIAR) have identified leafy greens of exceptional nutritional content in Pacific countries and northern Australia (Lyons, 2010; Lyons et al, 2015), and published fact sheets on these (Goebel et al, 2013; Lyons et al, 2018a).

“Future food production will come from *dualistic* agriculture: the subsistence sector will continue to support those living in rural areas, while modern agriculture and intensified production will need to support urban dwellers” (Benjamin et al, 2001). This statement has proved prescient.

***Human nutrition, health, epidemiology***

The *demographic transition*, a process by which a country moves from high to low birth rates and death rates, is often accompanied by rapid urbanization, and this is the case in PNG. This has resulted in a dichotomy of diet, physical activity and resultant disease profiles between urban and rural dwellers. This will be examined below.

Here is an example of these dietary differences:

**Table 1**. Some foods in the diet of rural and urban dwellers, 1996, % of population

Rural Urban Total PNG

Greens 74 79 75

SP 65 34 60

Rice 26 87 35

Temu and Saweri (2001). Although dated, this mostly reflects the current consumption pattern for these foods (M Bourke, pers comm, 2018).

Papua New Guinea has some of the worst health indicators in the world ([www.health.gov.pg](http://www.health.gov.pg)); e.g. see Table 2. For burden of disease, PNG was ranked 15th (last) against comparable countries, which included Nicaragua, Pakistan, Solomon Islands, Nigeria and Cameroon ([www.healthdata.org](http://www.healthdata.org)).

**Table 2.** PNG infant and maternal mortality rates and life expectancy

PNG Aust

Infant mortality rate (deaths/1000 live births over 1 year): 42 3

Maternal mortality rate (maternal deaths/100,000 live births: 215 7

Life expectancy (years) 66 83

[www.aihw.gov.au](http://www.aihw.gov.au) ; [www.knoema.com](http://www.knoema.com) ; [www.indexmundi.com](http://www.indexmundi.com) ; [www.countryeconomy.com](http://www.countryeconomy.com) .

Malnutrition is a basic cause of poor health and increased mortality rates, especially in poor rural areas of PNG, and particularly in the most vulnerable groups: infants, children under five years, and pregnant and post-partum women (Benjamin et al, 2001; Hanson et al, 2001; [www.health.gov.pg](http://www.health.gov.pg) ). Stunting (low height for age), and also wasting (low weight for age) in certain areas, is common, with prevalence often c 50% (Temu and Saweri, 2001; King and Mascie-Taylor, 2002; [www.health.gov.pg](http://www.health.gov.pg) ; Salmang, 2017; Schmidt et al, 2018). This reflects malnutrition, in particular low protein intake together with, in poorer households, an energy deficit due to lack of concentrated energy sources such as fats and oils (Bourke pers comm 2018; Schmidt et al, 2018). Furthermore, protein deficiency is usually accompanied by deficiencies of other nutrients (e.g. Ca) and micronutrients (e.g. vitamin A, B vitamins, Fe, Zn, I; see more detailed discussion below).

This deficient diet is associated with repeated and often chronic infectious illness/disease episodes, and the five-year child mortality rate can be as high as 43% in some areas. Preventable and treatable conditions, including malaria, pneumonia, diarrhoea, TB and neonatal sepsis are the most frequent causes of childhood deaths, and there are even occasional cholera outbreaks (Hide et al, 1992; Allen and Bourke, 2009; Rosewell et al, 2013; [www.health.gov.pg](http://www.health.gov.pg) ; [www.worldvision.com.au](http://www.worldvision.com.au) ; M Bourke, pers comm, 2018; Schmidt et al, 2018). Health services are poor across PNG, especially in rural areas, e.g. one doctor per 17,100 people, compared to Australia with one for 302 people (World Vision, 2017). The Schmidt et al (2018) study was a timely survey of food systems and disease in four rural areas (including southern Bougainville), sponsored by IFPRI and World Vision.

In addition to malnutrition, lack of health services, poor sanitation and contaminated drinking water, suboptimal breastfeeding/weaning practices contribute to stunting and infant/childhood deaths. Nearly 20 years ago, it was claimed that the biggest single cause of infant malnourishment in the highlands was informal adoption by nonlactating women and the consequent loss of milk supply of biological mothers (Benjamin et al, 2001), and this remains an issue (Schmidt et al, 2018).

In common with most developing countries in the early 21st century, PNG is experiencing the effects of the *epidemiological transition* from predominantly infectious diseases to so-called “lifestyle”, non-communicable diseases (NCD), accompanied by the well-known *double burden* of malnutrition (Temu and Saweri, 2001). Other researchers describe a *triple* burden, comprising *standard* *undernutrition* (protein-energy malnutrition), MND and *overnutrition*. However, this phenomenon is not uniform in PNG as NCD are overshadowed by infectious diseases in rural areas (Hide et al, 1992; [www.health.gov.pg](http://www.health.gov.pg) ; M Bourke, pers comm, 2018). But NCD will increase in importance with time in the rural sector, as shown by the recent IFPRI-World Vision survey, which found that the wealthier rural households were eating c 20% more than the recommended intake, with a higher intake of grain-based foods such as rice, pasta (two-minute noodles) and flour, thus trending toward a PNG urban diet (Schmidt et al, 2018).

Diabetes, hypertension, heart disease, obesity and certain cancers that comprise NCD are well established in the urban PNG population, to the extent that they now feature prominently in national morbidity and mortality statistics, even though urban/peri-urban dwellers comprise just c 23% of the total population ([www.health.gov.pg](http://www.health.gov.pg) ; [www.healthdata.org](http://www.healthdata.org)).

The “disability-adjusted life year” (DALY) is a useful measure for quantifying the magnitude of ill health. DALYs lost enable the addition of morbidity and mortality outcomes, and comprise an annual measure of disease burden. A public health intervention is expected to reduce the number of DALYs lost, and the extent of such a reduction is a measure of the benefit of the intervention (Meenakshi et al, 2007). The latest (2016) causes of DALYs lost in PNG (in declining order of importance) are lower respiratory infections (which include pneumonia, bronchitis, influenza and whooping cough), ischaemic heart disease, cerebrovascular disease, chronic obstructive pulmonary disease, neonatal/pre-term birth complications, and diabetes. The risk factors driving the most DALYs lost are malnutrition, tobacco, air pollution, dietary risks [I would have thought this overlaps with malnutrition], high fasting plasma glucose (up 41% from 2005), high body mass index (BMI) (+34%), high total cholesterol (+33%), alcohol and drug use (+16%) ([www.healthdata.org](http://www.healthdata.org) ).

Although most infectious diseases have decreased in recent years, this is not the case for HIV/AIDS (+2800% from 1990-2010, and now contributing over 3% to total Years of Life Lost (YLL, a measure of premature death), similar to TB ([www.healthdata.org](http://www.healthdata.org) ). Most new HIV cases are from the highlands, the National Capital District and Morobe (Allen and Bourke, 2009; [www.health.gov.pg](http://www.health.gov.pg) ). The sexually transmitted infection (STI) and HIV infection rate is the highest in the Asia-Pacific region ([www.health.gov.pg](http://www.health.gov.pg) ).

***Caveat***

A word of warning: any organization planning to invest in PNG needs to be aware of the country’s history of egregious political and government corruption. A recent example was the purchase of 40 new Maseratis and three Bentley limousines for the November 2018 APEC meeting in Port Moresby, to which Australia contributed over A$130 million (Packham, 2018). And this in a country where most rural dwellers hover around the poverty line and regional hospitals and clinics are chronically short of basic supplies. The PNG kleptocracy is often excused by apologists who refer to the country’s “virtually ungovernable” status: difficult terrain, a capital connected only to the provinces of Central and Gulf by road (thus limiting the range of the Maseratis and Bentleys), and numerous tribal groups with c 800 languages. However, PNG was justly and efficiently administered by Australia from the end of WW1 until independence in 1975.

**MICRONUTRIENT DEFICIENCIES IN PNG: VITAMIN A, ZINC, IRON**

**General**

Micronutrient deficiencies, especially Fe, vitamin A, Zn and I, afflict more than two billion individuals, or one in three people, globally (Bouis and Saltzman, 2017; Abeywickrama et al, 2018). Multiple MND and MND linked to protein and protein-energy deficiencies are common (Abeywickrama et al, 2018).

Widespread stunting in PNG, especially in rural areas, associated with diets deficient in protein and micronutrients, was discussed above. World Vision includes, under actions to improve maternal and child health, “providing micronutrient supplements, e.g. vitamin A, Zn, Fe and I”. The organisation conducts a *Madang Nutrition for Healthy Children* project ([www.worldvision.com.au](http://www.worldvision.com.au) ), which would provide a suitable collaborator to provide and promote biofortified crops (below). And a 2017 newspaper article observes that most of the children in hospitals in the country suffer from severe acute malnutrition, involving MND, including vitamin A, iodine and iron deficiencies, and anaemia. There has been little change since the 1980s (Salmang, 2017). A comparative study found that there are probable deficiencies of Fe, Zn, Ca and vitamin A in PNG (Gibson and Cavalli-Sforza, 2012).



Sweet potato trial conducted by ACIAR and World Vision, Madang, PNG 2008

The multifactorial nature of most illnesses/diseases in PNG children is illustrated by the study of Manning et al (2012), which concludes: “Severe anaemia is multifactorial in PNG children, strongly associated with undernutrition and common infections, and potentially preventable through vitamin A supplementation, improved nutrition, completion of vaccination schedules and intermittent preventative antimalarial treatment.” Special consideration is needed for infants and young children. The transition period from breast milk or formula to solid foods is often accompanied by MND in many developing countries (Bouis et al, 2017a).

For this study I was instructed to focus on the potential to deploy these HarvestPlus biofortified crops: orange sweetpotato (OSP), orange maize and Zn-rice, hence I needed to examine deficiencies of vitamin A and Zn in the country. Having noted the importance of Fe deficiency in PNG, I have taken the liberty of elaborating on this below, and including Fe-beans, another HarvestPlus biofortified crop, in this study. Iodine deficiency has been studied in PNG for a long time, and is still an issue, so I mention it briefly below, along with selenium (Se), a particular interest of mine. Selenium and I deficiencies, if concurrent, can be synergistically alleviated by joint fortification and/or agronomic biofortification (Lyons, 2018b).

*Selenium*

Two studies have found low levels of Se. One found Se levels in PNG children comparable with those of Malawi, a notably low-Se country (Donovan et al, 1992), and the other found Se deficiency associated with peripheral neuropathy (Rosewell et al, 2013). More research needed.

*Iodine*

Mountainous terrain far from the sea is commonly low in I, and the PNG highlands are no exception. Among earlier studies, it was found that a single 4ml injection of iodized oil (containing 2.2g I) corrected I deficiency for 4-5 years (Buttfield and Hetzel, 1967). Nearly 30 years later, Pharoah and Heywood (1994) reported that goitre appeared under control in parts of Madang Province, even though a decade had elapsed since provision of iodized oil.

More recent studies suggest that I deficiency is still a problem in PNG, especially in rural/remote areas: I deficiency was observed in 88% of children and 80% of women sampled: there was limited dietary diversity and restricted implementation of the universal salt iodization strategy (Goris et al, 2017). Amoa et al (1998) also reported that lack of iodized salt was an issue then, thus little has changed, and even in Port Moresby, low I intake is prevalent (Temple et al, 2006).

**Vitamin A**

There is abundant evidence of vitamin A insufficiency in PNG, if not clinical deficiency (Mueller, 2001; Jeganathan and Verma, 2017), even in children in the Port Moresby vicinity (Temple et al, 2011), associated with reduced immunity, night blindness and increased severity of malarial episodes (Manning et al, 2012; Shankar et al, 1999). Vitamin A (or Zn) supplementation may be an effective low-cost strategy to lower morbidity due to the malarial parasite, *Plasmodium falciparum* in young children (Shankar et al, 1999; Mueller, 2001), while a food system approach would probably be more effective and sustainable in the long term (Lyons, 2014).

It is estimated that 3% of the mortality of young children globally, 20% of corneal scarring and measles and all night blindness is due to vitamin A deficiency (Meenakshi et al, 2007). Using the mean DALYs lost to each of vitamin A, Fe and Zn deficiency in the countries presented in this article (which are similar in development terms and MND to PNG) to obtain values of DALYs as % of population, and using a total population of 8.4 million, it is estimated that 42,000, 33,600 and 25,200 DALYs are lost due to deficiencies of vitamin A, Fe and Zn, respectively, for a total of 101,000 DALYs lost; hence it is worthwhile to alleviate all of these deficiencies in PNG.

**Zinc**

The current Zn reference intake for humans is 2.5-2.9 mg Zn/day (Bouis et al, 2017b). As is the case for vitamin A, there is ample evidence that this level is not reached by a large proportion of the PNG population (Hide et al, 1992; Gould et al, 2013; Rosewell et al, 2013; Temple et al, 2015). It is recommended that Port Moresby women should eat more meat, poultry, eggs, dairy…and take Zn supplements (Temple et al, 2015). Shankar et al (2000) found that Zn supplements (10 mg/day given to 274 children aged 6-60 months, many with low baseline Zn level) reduced malarial episodes by 38%, while other researchers concluded that it is possible that Zn deficiency is associated with HIV infection in children, but the efficacy of Zn supplementation to HIV-infected children needs further study (Zhang et al, 2015).

Zinc deficiency is implicated in adverse functional outcomes associated with diarrhoea, pneumonia and stunting in children. An estimated 20% of diarrhoea, 40% of pneumonia and 4% of mortality of children under six years can be attributed to Zn deficiency (Meenakshi et al, 2007). There is a need for more Zn in diets, especially for vulnerable population sub-groups.

**Iron**

Iron deficiency reduces physical activity (in all age groups) and impairs mental development (in children under 6 years). Around 5% of all maternal mortality is caused by Fe deficiency. Only a percentage of all anaemia cases are attributed to Fe deficiency (often 50% is used), as anaemia may have multiple causes, including inflammation, vitamin A insufficiency, socioeconomic status and age (Meenakshi et al 2007; Wirth et al, 2017).

Several studies have reported high rates of anaemia in PNG (Shinoda et al, 2013; Goris et al, 2017), including 54% prevalence in infants in Kamea, Gulf Province, where dietary diversity was limited (Goris et al, 2017).

Studies have found possible protection afforded by Fe deficiency against malaria (Oppenheimer et al, 1986; Goheen et al, 2016), but most studies have not found Fe supplementation significantly associated with increased malaria risk (Muller et al, 2002; Moya-Alvarez et al, 2016; Neuberger et al, 2016; Lombardo et al, 2017). Iron supplementation needs to be integrated with other strategies to prevent or treat infections and undernutrition in pregnancy to achieve improvement in birth outcomes (Fowkes et al, 2018). A preferable strategy is to supply more Fe via food systems, e.g. using biofortified high-Fe beans (see below).

**OPPORTUNITIES FOR *HARVESTPLUS* BIOFORTIFIED CROPS TO REDUCE MND IN PNG**

**Background**

Biofortification is a promising, cost-effective and sustainable method to deliver micronutrients to a population that has limited access to diverse diets (Graham et al, 2007; Bouis and Welch, 2010; Garg et al, 2018). No single intervention will alleviate micronutrient deficiencies, and biofortification complements existing interventions, such as supplementation and industrial food fortification (Bouis and Saltzman, 2017), which are mostly absent in PNG.

Efficacy of all of the currently promoted biofortified crops has been demonstrated (Bouis et al, 2017a,b; Bouis and Saltzman, 2017). Examples include increased body vitamin A from production and consumption of OSP at village level in Mozambique (Low et al, 2007); OSP reduced the prevalence and duration of diarrhoea in children under five years in Mozambique (Jones and de Brauw, 2015); increased haemoglobin and total body Fe after eating Fe-beans for 4.5 months in Rwanda (Haas et al, 2016), and three months’ consumption of orange maize increased total body stores of vitamin A in children in Zambia, as effectively as supplementation (Gannon et al, 2014).

HarvestPlus’s *Biofortification Priority Index* (BPI) lists Papua (part of Indonesia, adjacent to PNG) as “top” for Zn-rice, “high” for orange maize, and “medium” for OSP and Fe-beans ([www.harvestplus.org](http://www.harvestplus.org)).

The suitability and potential of the following HarvestPlus biofortified crops for PNG will now be discussed: OSP, orange maize, Zn-rice and Fe-beans.

**OSP**

Orange sweetpotato is the most successful example of biofortification. Improved OSP varieties, developed by CIP, HarvestPlus and partners are now widely grown and eaten in over 19 sub-Saharan countries, including Uganda, Mozambique, Tanzania, DRC and Rwanda. They are high yielding, virus resistant and drought tolerant, and can provide 50-100% of individual vitamin A requirement; e.g. “one ice-cream scoop worth provides a child’s daily dose of vitamin A” (Bouis et al, 2017b; [www.harvestplus.org](http://www.harvestplus.org)). Cost-effectiveness data are available for OSP in Uganda, where biofortification was demonstrated to cost US$15-$20 per DALY saved, which the World Bank considers highly cost effective (Bouis and Saltzman, 2017).

CIP and other organizations have a range of OSP, a number of which would no doubt be able to contribute useful germplasm to NARI’s SP breeding program. For example, CIP’s *Carrot, Jewel, Resisto, Zambezi, Caromex* and *CN-1424-9* are all high-yielding with high b-carotene (376-1038 mg/kg DW. Furthermore, *CN-1424-9* yields well at high altitude (Kapinga et al, 2010), a trait that could be exploited for this zone in PNG. Another OSP that could be successful in PNG is *Solo Gold* (*UMUSPO 4*), released by Nigeria’s National Root Crops Research Institute and CIP, with high dry matter, tolerance to SP weevil, resistance to SP viral diseases and early maturity (Maru, 2018). Further suitable OSP (*Kamalsundari* and *BARI SP-5*) have been identified in Bangladesh (Islam et al, 2016).

Sweetpotato, as noted above, is by far the most important food crop in PNG, and in the highlands, consumption of as much as 2kg per day by adults is common (M Bourke pers comm 2018); well under this intake of OSP containing c 250 mg/kg DW of beta-carotene, would satisfy daily vitamin A need. Currently, there are some local OSP varieties as well as imports like *Beauregard* (bred by Louisiana State University). However, few OSP are grown or eaten in PNG, being less popular than drier white varieties (M Bourke pers comm, 2019).

One of the most important advantages of SP is that it produces well on soil of moderate or even low fertility, unlike taro, which only produces a reasonable yield on very fertile soils. Two or sometimes three consecutive plantings of SP are possible in lowland environments before yields decline to unacceptably low levels, and multiple plantings are possible in most highland locations. In contrast, only one planting of taro is usually possible in both lowlands and highlands (Bourke, 2006). It is difficult to measure SP yields under village conditions due to progressive/sequential harvesting methods; yields are often higher in the highlands, but are highly variable (Bourke et al, 2009), ranging from crop failure (0) to 50 t/ha, but are usually 5-30 t/ha (Bourke 1985, Sowei et al, 1992).

The food security aspect of SP production is improved where farmers are able to produce for both subsistence and cash-earning purposes (Bang and Kanua, 2001). An important current ACIAR project in PNG supports commercial SP production and marketing in the highlands and aims to sustainably increase the contribution that SP makes to cash income and food security, by improving SP value chains. The project is, in effect, turning subsistence SP production into market-oriented production, and its quality components include methods for provision of virus-free planting material and improvements in storage and transport, to maintain quality ([www.aciar.gov.au/project/HORT/097](http://www.aciar.gov.au/project/HORT/097)). This latter is of particular importance for OSP, as processing losses and degradation over time are usually substantial for provitamin A (Meenakshi et al, 2007; Bouis et al, 2017b). The ACIAR project runs from 2016 to 2021, thus could be a useful collaborator for HarvestPlus.

The higher the level of consumption of a given staple food (including how many people consume the staple and how frequently), the greater the impact of any given increment in micronutrient intake. The coverage rate, or the proportion of biofortified staples in production and consumption (compared to non-biofortified), is an important determinant of the magnitude of impact (Meenakshi et al, 2007). Because OSP is substantially higher in b-carotene (e.g. *Beauregard* 235 mg/kg DW, equivalent to about 55 mg/kg FW or 6 mg/100g FW, and CIP’s *Resisto* is much higher still, with 1030 mg/kg DW) than orange maize (see below), and much more SP than maize is consumed, OSP has a much greater potential than orange maize to alleviate vitamin A deficiency in PNG. To further bolster the rationale for OSP as the most suitable vehicle for enhancing population vitamin A status in PNG, a survey found child growth was better in food systems based on SP and cassava than in those where banana, sago and taro are staples (Mueller, 2001).



Solomon Islands farmer with his *Beauregard* OSP harvest, Guadalcanal 2010

*Beauregard* was introduced to Solomon Islands under a HarvestPlus/ACIAR OSP project (Lyons et al, 2010) and has become popular with farmers and consumers. Reasons for discarding some previous imported SP germplasm include low yield, susceptibility to wilt/scab disease (a common SP disease in Melanesia caused by the fungus *Elsinoe batatas*), high tuber cracking, irregular tuber shape, low dry matter and poor taste. Insect pests include the SP weevil (*Cylas formicarius*), hawkmoth (*Agrius convolvuli*) and the SP leaf miner (*Bedellia somnulentella*). Weevil infestation is more common during droughts (van Wijmeersch, 2001). CIP/HarvestPlus varieties with b-carotene levels comparable with or higher than local OSP, in addition to being starchier, high yielding and resistant to viruses and wilt could make an impact in PNG. They could be trialled initially in collaboration with NARI, which has a well-established poly-cross program at Aiyura (highlands), and has trialled OSP previously (Lyons et al, 2010; Wera et al, 2014). The Bubia experimental station near Lae would provide a suitable lowland trial site.

**Vitamin A maize**

Vitamin A (orange) maize varieties have been released in several sub-Saharan countries, including Zambia and Nigeria, and contain 7-15 mg/kg b-carotene DW, with 15 mg/kg being the HarvestPlus target. Some experimental maize lines, not yet in high-yielding backgrounds, contain more than 30 mg/kg provitamin A carotenoids (Bouis et al, 2017a). Orange maize is efficacious (Palmer et al, 2016) and can provide up to 25% of daily vitamin A requirement; several varieties are high yielding, disease resistant and drought tolerant ([www.harvestplus.org](http://www.harvestplus.org) ; W Pfeiffer, pers comm, 2018).

The largest global maize genetic resources are held at CIMMYT and IITA, totalling around 30,000 maize seed samples (Menkir et al, 2018; [www.iita.org](http://www.iita.org) ; [www.cimmyt.org/germplasm-bank](http://www.cimmyt.org/germplasm-bank) ). IITA lists 20 orange maize types among its 1561 accessions. These are open-pollinated lines/varieties bred in partnership with the Institute for Agricultural Research in Nigeria, funded by HarvestPlus ([www.iita.org](http://www.iita.org) ; [www.allafrica.com](http://www.allafrica.com)). They have been bred and trialled at low altitude, tropical locations which assists selection for disease resistance/tolerance, so a number of them may be suitable for PNG (W Pfeiffer, pers comm 2018).

Yellow maize is an important crop throughout PNG, grown mostly for human consumption of fresh grains (corn on cobs) rather than for dried seeds/flour. Consumption per person is, however, much lower than in a country like Zambia (Bouis et al, 2017a). It is commonly grown as an intercrop with other food crops, and in the highlands it is grown in rotation with SP and peanuts. Maize is a relatively recent introduction to PNG, in the 19th century. Although not as important as SP in the highlands and banana and sago in the lowlands (highest total smallholder production c 235 tonnes in 2009), it is nevertheless grown by 94% of farmers (Sip and Gendua, 2014).

No yield data exist for village plantings. Maize has been grown commercially for over 30 years in the Markham and Ramu valleys, the most suitable places in PNG for larger-scale grain production, where yields were reported as 2.5 t/ha in 1976 (Bourke et al, 2009). Yields of up to 9.2 t/ha were reported from small experimental plots using imported varieties (yields usually range from 2-6 t/ha). Seeds from village-planting usually give low yields when grown under experimental conditions, due to the reasons noted below. There are two largish-scale maize producers in PNG: Rumion Piggery and Trukai Farms, which cultivate 500-1000 ha of maize each in the Markham Valley. Most of their maize is used for animal feed (Sip and Gendua, 2014).

Due to the open-pollinated nature of the maize crop and strong inbreeding depression, the *true to type* traits of the original variety are lost during repeated cultivation of the same variety in a farming system (in the absence of seed replacement). This, combined with lack of proper seed purity control, has resulted in a shortage of high-yielding maize varieties. In order to diversify the cropping system and improve maize yield, seed of new open pollinated varieties (OPV) needs to be introduced every three to four years. Hybrid maize generally performs better than OPV in terms of agronomic traits, pest and disease resistance and yield, due to heterosis; however, farmers need to buy seed for each planting (Sip and Gendua, 2014).

Although the level of beta-carotene in orange maize (10-15 mg/kg DW) is well below that in many OSP varieties, there is an opportunity for HarvestPlus’s orange maize in PNG. Although efforts have been made over the years, including introduction of numerous CIMMYT lines/varieties, these have met with limited success in terms of varietal development, due to lack of proper seed production, management and distribution system; lack of seed storage facilities; limited technical capacity; lack of proper documentation of research, and high cost of hybrid seeds from commercial companies (Sip and Gendua, 2014). Trials of orange maize could be conducted by NARI at Bubia (lowland) and Aiyura (highland). Maize is a popular crop and any improvement in quality, adaptability and productivity will make it even more popular, and NARI is keen to trial new varieties.

**Zinc rice**

An initial screening of 939 rice genotypes by the International Rice Research Institute (IRRI) found a range of 15-58 mg/kg Zn (and 8-24 mg/kg Fe) in brown rice. HarvestPlus has now screened over 7500 rice lines. HarvestPlus’s baseline rice grain Zn in the initial target countries of Bangladesh and India is 16 mg/kg. Using their target increment of +12 mg/kg, a target in biofortified Zn-rice of 28 mg/kg (and 13 mg/kg Fe) in polished rice, to reach 30% of the estimated average requirement (EAR), was arrived at. Varieties released by the Bangladesh Rice Research Institute (BRRI) include BRRI dhan 62 and 64, which are high yielding, disease and pest resistant and early maturing, with higher Zn levels, e.g. BRRI dhan 62 contains 20 mg/kg Zn in polished grain, compared with around 16 mg/kg in local varieties grown on the same soil. BRRI dhan 64 is a short duration variety for the wet season (100 days compared to 140 days), which allows production of a third crop of lentils between wet and dry season rice crops. Another BRRI variety released in 2014 contains 22 mg/kg Zn (Graham et al, 1999; Bouis and Saltzman, 2017; [www.harvestplus.org](http://www.harvestplus.org)). Higher Zn levels have been obtained using transgenics, up to 46 mg/kg in field-grown polished rice (Trijatmiko et al, 2016), and even 56 mg/kg in BC2F2*japonica/japonica* progeny (Moreno-Moyano et al, 2016), but to date the highest Zn levels are found in lower-yielding material.

Although a Zn-rice efficacy trial is yet to be reported, a biofortified Zn-wheat trial (chapati) in India found children (n=3000, 4-6 years) who ate the high-Zn wheat (30 mg/kg) experienced 17% fewer days with pneumonia and 39% fewer days vomiting, compared to children who consumed a lower Zn, conventional wheat (20 mg/kg). There was no difference in Zn status between the two groups post-intervention (Sazawal et al, 2018).

Rice for local consumption is grown in small quantities in a number of PNG provinces. For example, total production in 2006 was less than 1000 tonnes. Under broadacre farming conditions in the upper Markham and Ramu valleys, yields were reported at 2 t/ha in the late 1970s. Bourke reports that rice is the most researched and most controversial agricultural crop in PNG. Rice imports have been in the range 120,000 – 208,000 t/yr between 1990 and 2005, mostly from Australia. In contrast, domestic rice production has been in the range 60-2,200 t/yr from 1962 to 2000, averaging about 400 t/yr since 1980. “Claims are made for significant local production from time to time, but these are political statements rather than realistic estimates.” Since 1977, domestic rice production has not exceeded 2% of the total of rice imported (Blakeney and Clough, 2001; Bourke et al, 2009; [www.trukai.net](http://www.trukai.net)).

Rainfall is too unreliable in some locations in PNG for perennial, unirrigated rice production. The high capital costs of establishing irrigated paddy fields and high production costs per tonne constrain development of a PNG rice industry. The most important single reason that rice cultivation has not become significant in PNG is its relatively low return for labour input. Furthermore, where irrigated rice has been grown, pests, weeds and disease have severely reduced yields. The costs of establishing areas sufficient to replace imports would distort the PNG economy, require large subsidies and result in a substantial increase in the retail cost of rice in PNG. Economists have concluded that PNG is better off to import cheap rice and to export high quality palm oil, coffee and cocoa, than to try to establish a domestic, import-replacement rice industry (Gibson, 1993; Blakeney and Clough, 2001; Bourke et al, 2009).

Most of the rice consumed in PNG is imported from Australia (c 200,000 tonnes per annum) (Bourke and Vlassak, 2004). The brand *Roots*, imported and sold by Trukai, accounts for almost 90% of sales. It is made up of mixed quality grain, with a high proportion of broken grain that other markets will not accept (Bourke and Vlassak, 2004). Trukai is two-thirds owned by Australia’s *SunRice* and the rest by investment trustee *MTSL* (which has 40,000 PNG unit holders), and currently supplies 75% of the market ([www.jica.go.jp](http://www.jica.go.jp) ; [www.trukai.net](http://www.trukai.net) ). *SunRice* rice imported from Australia may contain rice grown in other countries (e.g. Indonesia, Vietnam, Thailand), as well as rice grown in Australia (C Blanchard, pers comm 2018).

Most of Australia’s rice is grown in the Riverina region of New South Wales, on heavy clay soils, to limit seepage, with topsoil pH of 7-8.5 and subsoil 9.0. The production system is promoted as “the most water-efficient rice production in the world”. The cultivated area of c 52,000 ha produces c 819,000 tonnes per annum, of which 85% is exported (Bajwa and Chauhan, 2017; E Tavakkoli, pers comm 2018; [www.rga.org.au](http://www.rga.org.au)).

We need to compare the current Zn levels of polished rice consumed in PNG with that of Zn-rice (c 22 mg/kg) in order to determine whether Zn-rice has a chance of making an impact on Zn intake in PNG. An estimate for PNG-consumed rice can be made, using a combination of previous studies (Marr et al, 1995) and the findings of my recent small survey of retail rice samples (Adelaide, November 2018) (Table 3).

Analyses of 90 samples of brown rice collected from commercial crops in the irrigated rice-growing regions of Australia in 1991/92 revealed a Zn range of 15-24 mg/kg in brown rice (6-78 mg/kg for Fe), with means from previous studies of Zn 19 and Fe 15 (Marr et al, 1995). The 1991/92 mean of c 19 would equate to a level in polished rice of c 14 mg/kg, using 73% Zn retention post-milling (and 4 mg/kg Fe, using 24% retention) (Martinez et al, 2010).

**Table 3.** Zinc and iron concentrations in rice samples purchased from Coles, Burnside supermarket, November 2018, compared with Marr et al (1995). Analysis by ICP-OES. Units: mg/kg

**Category Name Origin Zn Fe**

Black Sunrice Thailand 19 11

Brown Coles Aust Australia 17 9

Sunrice Aust Australia 14 8

Riviana basmati Pakistan 14 17

Marr et al (1992) Australia 19 15

**Mean (brown) 16 12**

White Coles jasmine Thailand 12 3

Sunrice jasmine Australia 10 2

Black & Gold Vietnam 13 4

Marr et al (1992) est. Australia 14 4

**Mean (white) 12 3**

A higher proportion of Fe than Zn is lost in milling to white rice; other minerals which are mostly lost include Mg (c 90%) and K (c 70%). This exercise provides a plausible estimated level of 12 mg/kg Zn in polished rice consumed by people in PNG. Thus there is a differential of 10 mg/kg between this and Zn-rice. To estimate the amount of Zn contributed to the daily diet by “standard” rice compared with Zn-rice, I have used these figures: standard polished rice: 12 mg/kg Zn; HarvestPlus Zn-rice: 22 mg/kg Zn; PNG population: 8.4 million; total rice consumed by people in PNG per annum: 235,000 tonnes. This yields an estimate of 77 g rice/person/day, which would of course be highly variable, e.g. more rice is eaten by urban/peri-urban dwellers than by rural dwellers (see Table 1 above), and the latter usually have lower dietary Zn intake. If this were standard rice it would provide 0.92 mg Zn; if Zn-rice: 1.7 mg Zn. Then using a bioavailability figure of 36% (derived from Wei et al (2012) and Trijatmiko et al (2016), who used 25%, and taking the mean of these studies), standard rice would provide c 0.33 mg, and Zn-rice 0.61 mg Zn/day, an additional 0.28 mg Zn/day. Although these levels appear modest, the Zn-rice would contribute 24% of the daily Zn reference intake of 2.5 mg (lower level of the 2.5-2.9 mg range (Bouis et al, 2017b), which represents a worthwhile contribution to dietary bioavailable Zn.

Another factor to consider is that soil Zn deficiency is common, together with Mn deficiency, in high pH highland soils (Hartemink and Bourke, 2000). Thus, although Zn-rice could be trialled in PNG (e.g. by Trukai and NARI, alongside current popular varieties), it may struggle to replicate levels of 22 mg/kg Zn (in polished rice) on Zn deficient highland soils. In any case, it is likely that imports will be much greater than local rice production for the foreseeable future.

**Iron beans**

Given the prevalence of low-Fe diets and Fe-deficiency anaemia in PNG (discussed above), I have included Fe-beans in this study although they were not on HarvestPlus’s focus list for PNG.

Limited variation found for Fe in wheat, maize and rice (especially in their milled forms) means that the Fe target level for these crops cannot be achieved via conventional breeding (Trijatmiko et al, 2016). Useful variation has been found in beans, however. Over ten varieties of Fe-beans have been released in Rwanda since 2011, with c 700,000 farmers growing them by 2014, and just five years after the first Fe-bean release, they make up more than 10% of national bean production in Rwanda (Asare-Marfo et al, 2016). Fe-beans are also grown in Uganda and eastern parts of the Democratic Republic of Congo. They can provide up to 45% of daily Fe requirement and are high yielding, virus resistant and heat and drought tolerant ([www.harvestplus.org](http://www.harvestplus.org)). In Rwanda, Fe levels in these beans has reached 86 mg/kg (Haas et al, 2016), though 72 mg/kg is more usual, compared with a mean of 43 mg/kg for local Rwandan beans. Embrapa’s biofortified beans in Brazil contain 73 mg/kg Fe compared with 57 mg/kg in common local beans ([www.harvestplus.org](http://www.harvestplus.org) ; Asare-Marfo et al, 2016); Mulambo et al, 2017). In a trial in Rwanda in which women (86% of whom were Fe-deficient and 37% anaemic at baseline) consumed Fe-beans (86 mg/kg) v standard beans (50 mg/kg), the Fe-bean group had higher haemoglobin, ferritin and body Fe after 128 days, a significant improvement (Haas et al, 2016).

Although Rwandans consume a lot more beans than people in PNG, peanuts (*Arachis hypogaea*) are popular, especially in the highlands, intercropped or rotated with SP, maize and other food crops. Winged beans (*Psophocarpus tetragonolobus*) are also often grown: all parts are nutritious and they even produce tubers, which are substantially higher in protein and micronutrients than those of SP (e.g. 11% v 1.2% protein). Winged bean also nodulates more heavily than most legumes, and its beans are higher in protein than those of cowpeas, kidney beans and *Mucuna*, with Fe range 51-117mg/kg (Hale and Williams, 1978; Ekpenyong, 1984; Kadam and Salunkhe, 1984; Kayisu et al, 1984; Lepcha et al, 2017). Moreover, Fe and Zn in winged bean flour are relatively bioavailable (Hettiarachy and Erdman, 1984).

Leguminous hedgerows form a useful intercrop with SP and other food crops in PNG (Brook, 1999). A study of 64 peanut genotypes across eight environments in India found these ranges of Fe: 33-68 mg/kg and Zn: 44-95 mg/kg (Pasupuleti et al, 2014). I estimate legumes/beans/pulses in PNG to have Fe in the range 45-85 mg/kg. It is a question of whether the HarvestPlus Fe-beans have higher Fe than some of the popular PNG varieties. Again, trials could be conducted at NARI sites to assess their performance against local species and varieties.

**CONCLUSION**

**OSP**

Sweetpotato is easily the most important food crop in PNG and OSP varieties are already grown, in small quantities, at some highland locations. New varieties that are at least as high in b-carotene as the best local varieties and which have an added attraction such as higher starch, higher yield or improved disease resistance/tolerance (and ideally with all of these attributes), would be likely to become increase the popularity of OSP. Because OSP is a lot higher in b-carotene than orange maize, and much more SP than maize is consumed, OSP has a greater potential than orange maize to alleviate vitamin A deficiency in PNG.

**Orange maize**

Despite this, there is also an opportunity for orange maize in PNG. Maize is grown by most farmers, and due to the open-pollinated nature of most PNG varieties and no seed purity control, there is a lack of high-yielding maize varieties. Hence new, high-yielding, disease resistant/tolerant varieties of orange maize would be welcome, and would probably become widely grown. Most current maize varieties in PNG are yellow, and, given the popularity of OSP in the highlands, I doubt whether there would be any prejudice toward orange maize on the basis of colour. Be aware that previous imported varieties have had limited success due to the reasons noted above.

**Zn-rice**

With Zn insufficiency prevalent in PNG, I see a place for HarvestPlus Zn-rice (containing at least 22 mg/kg Zn, compared with c 12 mg/kg currently in polished rice) in PNG. In-country rice production is likely to remain low compared to imports, and I do not regard rice as a suitable smallholder subsistence crop in the long term in a country like PNG. Small rice plots are a magnet for insect pests, leading to the need for chemical pesticides, an unwelcome development for smallholders and the environment. Additionally, PNG highland soils are commonly Zn-deficient, which may impede the expression of Zn-rice’s high-Zn trait. Moreover, as most people prefer to eat polished rice, mills are required in numerous regional centres, and in PNG and Solomon Islands these have a history of inadequate maintenance and subsequent breakdown.

Nevertheless, this does not preclude Zn-rice with additional agronomic features (e.g. early maturity) being trialled in PNG (e.g. by Trukai Industries and NARI) alongside popular current varieties grown by smallholders. If Zn-rice could be imported (e.g. from Bangladesh, Thailand, Vietnam, Indonesia) in sufficient quantity, it would be likely to improve, i.a., the unacceptably high rates of stunting, especially in rural areas. Rice is consumed widely, the Zn differential between current rice consumed and Zn-rice is sufficient to make a difference, and imported rice is available in stores across the country. The key to success would be the ability to land Zn-rice in PNG at a price no higher than current imports, in order to be attractive to importers.

**Fe-beans**

Iron deficiency is a prevalent and severe MND in PNG. Moreover, more legumes in general, along with nutritious leafy greens such as aibika, drumstick, chaya and purslane, need to be grown and consumed in order to increase protein intake, especially where meat/fish/eggs are unavailable or too expensive.

HarvestPlus Fe-beans with > 70 mg/kg Zn could be trialled by NARI, alongside the best local varieties, including winged beans, which are highly nutritious and should be grown more widely.

**Iodine**

Finally, it should be noted that iodine deficiency remains an issue in much of PNG, due largely to lack of enforcement of universal salt iodization in recent decades. Unless this is addressed, benefits from improved supply of vitamin A, Zn and Fe are likely to be less than their potential.

**REFERENCES**

Abeywickrama HM, Koyama Y, Uchiyama M et al 2018. Micronutrient status in Sri Lanka: a review. *Nutrients* 10 (11): 1583. Doi 10.3390/nu10111583.

Allen B, Bourke RM 2009. People, land and environment. Pp27-127. In Bourke RM, Harwood T (eds) *Food and Agriculture in Papua New Guinea.* ANU E Press, The Australian National University, Canberra, Australia.

Amoa B, Pikire T, Tine P 1998. Iodine content of salt in Lae city of Papua New Guinea. *Asia Pacific Journal of Clinical Nutrition* 7: 128-130.

Asare-Marfo D, Herrington C, Alwang J et al 2016. Assessing the adoption of high-iron bean varieties and their impact on iron intakes and other livelihood outcomes in Rwanda: main survey report. International Food Policy Research Institute (IFPRI), HarvestPlus, Washington DC, USA.

Bailey J 2009. An evaluation of nutritional constraints on sweetpotato production in the Papua New Guinea highlands using the diagnosis and recommendation integrated system (DRIS). *ACIAR Technical Reports* Series Issue71: 110-117. Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia.

Bajwa AA, Chauhan BS 2017. Rice production in Australia. In Chauhan BS et al (eds) *Rice Production Worldwide*. Springer, Switzerland.

Bang S, Kanua M 2001. Pp 669-673. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Benjamin A, Mopafi I, Dube T 2001. Pp 94-99. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Blakeney M, Clough R 2001. Pp 23-29. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Bouis HE, Welch RM 2010. Biofortification – a sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Science* 50: S20-S32.

Bouis HE, Saltzman A 2017. Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security* 12: 49-58.

Bouis HE, Saltzman A, Low J et al 2017a. An overview of the landscape and approach for biofortification in Africa. *African Journal of Food, Agriculture and Nutrition* 17: 11848-11864.

Bouis HE, Saltzman A, Low J et al 2017b. The way forward. *African Journal of Food, Agriculture and Nutrition* 17: 12130-12141.

Bourke RM 1985. Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries* 33: 89-108.

Bourke RM 2001. An overview of food security in PNG. Pp 5-14. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Bourke RM, Vlassak V 2004. *Estimates of Food Crop Production in Papua New Guinea*. The Australian National University, Canberra, Australia.

Bourke RM 2006. Sweet potato in Papua New Guinea: the plant, agronomy and people. Pp 28-43. In RM Bourke and Johnston M (eds) *Proceedings of the Papua New Guinea Sweet Potato Workshop, Aiyura, May 2004. Australian contribution to the PNG National Agricultural Research System.* National Agricultural Research Institute (NARI), Lae, PNG.

Bourke RM, Allen B 2009. Introduction. Pp 5-9. In Bourke RM and Harwood T (eds) *Food and Agriculture in Papua New Guinea.* ANU E Press, The Australian National University, Canberra, Australia.

Bourke RM, Gibson J, Quartermain et al 2009. Food Production, Consumption and Imports. Pp 129-192. In Bourke RM and Harwood T (eds) *Food and Agriculture in Papua New Guinea.* ANU E Press, The Australian National University, Canberra, Australia.

Brook, R 1999. Interactions between leguminous hedgerows and a sweet potato intercrop in Papua New Guinea. *Tropenlandwirt* 100: 133-146.

Buttfield IH, Hetzel BS 1967. Endemic goitre in eastern New Guinea, with special reference to the use of iodized oil in prophylaxis and treatment. *Bulletin of the World Health Organization* 36: 243-262.

Donovan UM, Gibson RS, Ferguson EL et al 1992. Selenium intakes of children from Malawi and Papua New Guinea consuming plant-based diets. *Journal of Trace Elements and Electrolytes in Health and Disease* 6: 39-43.

Ekpenyong TE 1984. Composition of some tropical tuberous foods. *Food Chemistry* 15: 31-36.

Fowkes FJ, Moore KA, Opi DH et al 2018. Iron deficiency during pregnancy is associated with a reduced risk of adverse birth outcomes in a malaria-endemic area in a longitudinal cohort study. *BMC Medicine* 16: 156-166.

Fujinuma R, Kirchhof G, Ramakrishna A et al 2018. Intensified sweetpotato production in Papua New Guinea drives plant nutrient decline over the last decade. *Agriculture, Ecosystems and Environment* 254: 10-19.

Gannon B, Kaliwile C, Arscott SA et al 2014. Biofortified orange maize is as efficacious as vitamin A supplements in Zambian children even in the presence of high liver reserves of vitamin A: a community-based, randomized placebo-controlled trial. *American Journal of Clinical Nutrition* 100: 1541-1550.

Garg M, Sharma N, Sharma S et al 2018. Biofortified crops generated by breeding, agronomy, and transgenic approaches are improving lives of millions of people around the world. *Frontiers in Plant Nutrition* 5: 12. doi 10.3389/fnut.2018.00012.

Gibson J 1993. Rice self-sufficiency and the terms of trade: why rice is a good thing to import. *Economics Division Working Papers 93/96.* Research School of Pacific Studies, The Australian National University (ANU), Canberra, Australia.

Gibson RS, Cavalli-Sforza T 2012. Using reference nutrient density goals with food balance sheet data to identify likely micronutrient deficits for fortification planning in countries in the Western Pacific region. *Food and Nutrition Bulletin* 33: S214-S220.

Goebel R, Taylor M, Lyons G 2013. Feasibility studyon increasing the consumption of nutritionally-rich leafy vegetables by indigenous communities in Samoa, Solomon Islands and Northern Australia. ACIAR, Canberra, Australia. [www.growables.org/informationVeg/TopTenNutritiousLeafyVegetables.htm](http://www.growables.org/informationVeg/TopTenNutritiousLeafyVegetables.htm)

Goheen MM, Wegmuller R, Bah A et al 2016. Anemia offers stronger protection than sickle cell trait against the erythrocytic stage of *Falciparum* malaria and this protection is reversed by iron supplementation. *EBio Medicine* 14: 123-130.

Goris JM, Zomerdijk N, Temple VJ 2017. Nutritional status and dietary diversity of Kamea in Gulf Province, Papua New Guinea. *Asia Pacific Journal of Clinical Nutrition* 26: 665-670.

Gould C, Tousignant B, Brian G et al 2013. Cross-sectional dietary deficiencies among a prison population in Papua New Guinea. *BMC International Health and Human Rights* 13: 21-27.

Graham RD, Senadhira D, Beebe S et al 1999. Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. *Field Crops Research* 60: 57-80.

Graham RD, Welch RM, Saunders DA et al 2007. Nutritious subsistence food systems. *Advances in Agronomy*  92: 1-74.

Haas JD, Luna SV, Lung’aho MG et al 2016. Consuming iron biofortified beans increases iron status in Rwandan women after 128 days in a randomized controlled feeding trial. *The Journal of Nutrition* 1586-1592 doi 10.3945/jn.115.224741.

Hale PR, Williams BD (eds) 1978. Winged bean pp14-15. In *Liklik Buk: A rural development handbook catalogue for Papua New Guinea.* The Melanesian Council of Churches, Lae, PNG.

Hanson LW, Allen BJ, Bourke, McCarthy TJ 2001. *Papua New Guinea Rural Development Handbook.* The Australian National University (ANU), Canberra, Australia.

Hartemink AE, Bourke RM 2000. Nutrient deficiencies of agricultural crops in Papua New Guinea. *Outlook on Agriculture* 29: 97-108.

Hettiarachchy NS, Erdman JR 1984. Bioavailability of zinc and iron from winged bean seed flour. *Journal of Food Science* 49: 1132-1135.

Hide RL, Allen BJ, Bourke RM 1992. Agriculture and nutrition in Papua New Guinea: some issues. *Papua New Guinea National Nutrition Policy Workshop. Institute of National Affairs Discussion Paper No. 54.* Institute of National Affairs, Port Moresby, PNG.

Islam SN, Nusrat T, Begum P, Ahsan M 2016. Carotenoids and b-carotene in orange fleshed sweet potato: A possible solution to vitamin A deficiency. *Food Chemistry* 199: 628-631.

Jeganathan V, Verma N 2017. Vitamin A deficiency and malnourishment among young children in Papua New Guinea. *JSM Ophthalmology* 5(1): 1047-1051.

Jones KM, de Brauw A 2015. Using agriculture to improve child health: promoting sweet potatoes reduces diarrhea. *World Development* 74: 15-24.

Kadam S, Salunkhe K 1984. Winged bean in human nutrition. *Critical Reviews in Food Science and Nutrition* 21: 1-40.

Kapinga R, Tumwegamire S, Ndunguru J et al 2010. Catalogue of orange-fleshed sweetpotato varieties for Sub-Saharan Africa. International Potato Center (CIP), Lima, Peru.

Kapal DB, Taraken IT, Sirabis W 2010. Soil fertility management options in sweet potato based cropping systems in the highlands of Papua New Guinea. *Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world.* Brisbane, Australia, 1-6 August, 2010.

Kayisu K, Vanbelle M, Foulon M, Vervack W 1984. Estimation of the nutritional value of some cultivated legumes from Zaire. *Revue des Fermintations et des Industries Alimentaires* 39: 87-94.

King SE, Mascie-Taylor CG 2002. Nutritional status of children from Papua New Guinea: associations with socioeconomic factors. *American Journal of Human Biology* 14: 659-668.

Lepcha P, Egan AN, Doyle JJ, Sathyanarayana N 2017. A review on current status and future prospects of winged bean (*Psophocarpus tetragonolobus*) in tropical agriculture. *Plant Foods in Human Nutrition* 72: 225-235.

Lombardo P, Vaucher P, Rarau P et al 2017. Hemoglobin levels and the risk of malaria in Papua New Guinean infants: a nested cohort study. *American Journal of Tropical Medicine and Hygiene* 97: 1770-1776.

Low JW, Arimond M, Osman N et al 2007. A food-based approach introducing orange fleshed sweet potato increased vitamin A intake and serum retinol. *Journal of Nutrition* 137: 1320-1327.

Lyons G 2010. Screening and field trials of high-carotenoid sweet potatoes in Solomon Islands and Papua New Guinea to improve human vitamin A status. HarvestPlus, Washington DC, USA and ACIAR, Canberra, Australia. [www.adelaide.edu.au/directory/graham.lyons/](http://www.adelaide.edu.au/directory/graham.lyons/) Files: Solomon Islands PNG Orange Sweet Potato Program Final Report, 2010.

Lyons G 2014. Vitamin A. “Why weren’t we told this long ago?” *World Nutrition* 5: 1125-1126.

Lyons G, Goebel RG, Tikai P et al 2015. Promoting nutritious leafy vegetables in the Pacific and Northern Australia. *Acta Horticulturae* 1102: *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014):* International Symposium on Indigenous Vegetables. doi 10.17660/ActaHortic.2015.1102.31.

Lyons G, Dean G, Goebel, Taylor M, Kiata R, Tongaiaba R 2018a. Tackling NCDs from the ground up: nutritious leafy vegetables to improve nutrition security on Pacific atolls. Nutritious leafy vegetables factsheets 1-13. ACIAR, Canberra, Australia and The Pacific Community, Suva, Fiji. [www.thewaite.org/helping-the-pacific-to-eat-its-greens/](http://www.thewaite.org/helping-the-pacific-to-eat-its-greens/)

Lyons GH 2018b. Biofortification of cereals with foliar selenium and iodine could reduce hypothyroidism. *Frontiers in Plant Science*: 9, article 730 doi 10.3389/fpls.2018.00730.

Manning L, Laman M, Rosanas-Urgell A et al 2012. Severe anemia in Papua New Guinean children from a malaria-endemic area: a case-control etiologic study. *Neglected Tropical Diseases* 6(12):e1972 doi 10.1371/journal.pntd.0001972.

Marr KM, Batten GD, Blakeney AB 1995. Mineral elements in Australian brown rice. *International Rice Research Notes* 20(3): 17-18.

Martinez C, Borrero R, Taboade J et al 2010. Rice cultivars with enhanced iron and zinc content to improve human nutrition. *28th International Rice Research Conference, 8-12 November 2010.* Hanoi, Vietnam.

Maru J 2018. Sweetpotato Knowledge Portal: A new orange-fleshed sweetpotato to fight vitamin A deficiency in Nigeria. [www.sweetpotatoknowledge.org](http://www.sweetpotatoknowledge.org) Accessed 1st November 2018.

Meenakshi JV, Johnson N, Manyong VM et al 2007. How cost-effective is biofortification in combating micronutrient malnutrition? An *ex-ante* assessment. HarvestPlus Working Paper No. 2, August 2007. HarvestPlus, Washington DC, USA. [www.harvestplus.org](http://www.harvestplus.org)

Menkir A, Palacios-Rojas N, Alamu O et al 2018. Vitamin A-biofortified maize: exploiting native genetic variation for nutrient enrichment. *Science Brief: Biofortification no. 2 (February 2018).* CIMMYT, IITA, EMBRAPA, HarvestPlus, and Crop Trust. Bonn, Germany.

Moreno-Moyano LT, Bonneau JP, Sanchez-Palacios JT et al 2016. Association of increased grain iron and zinc concentrations with agro-morphological traits of biofortified rice. *Frontiers in Plant Science* 7: 1463.

Moya-Alvarez V, Bodeau-Livinec F, Cot M 2016. Iron and malaria: a dangerous liaison? *Nutrition Reviews* 74: 612-623.

Mueller I 2001. The spatial pattern of child growth in PNG. Pp 414-431. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Mulambo J, Andersson MS, Palenberg M et al 2017. Iron beans in Rwanda: crop development and delivery experience. *African Journal of Food, Agriculture, Nutrition and Development* 17: 12026-12050.

Muller O, Jahn A, von Braun J 2002. Micronutrient supplementation for malaria control – hype or hope? *Tropical Medicine and International Health* 7: 1-3.

Neuberger A, Okebe J, Yahav D et al 2016. Oral iron supplements for children in malaria-endemic areas. *Cochrane Database of Systematic Reviews* 2 Article CD006589.

Oppenheimer SJ, Gibson FD, Macfarlane SB et al 1986. Iron supplementation increases prevalence and effects of malaria: report on clinical studies in Papua New Guinea. *Transcripts of the Royal Society of Tropical Medicine and Hygiene* 80: 603-612.

Palmer AC, Healy K, Barffour MA et al 2016. Provitamin A carotenoid-biofortified maize consumption increases pupillary responsiveness among Zambian children in a randomized controlled trial. *The Journal of Nutrition* 146: 2551-2558.

Paspuleti J, Nigam S, Rathore A, Venuprasad R 2014. Iron and zinc concentrations in peanut (*Arachis hypogaea* L.) seeds and their relationship with other nutritional and yield parameters. *The Journal of Agricultural Science* 153: 1-20.

Pharoah PD, Heywood PF 1994. Endemic goitre and cretinism in the Simbai and Tep-Tep areas of Madang Province, Papua New Guinea. *Papua New Guinea Medical Journal* 37: 110-115.

Rosewell A, Clark G, Mabong P et al 2013. Concurrent outbreaks of cholera and peripheral neuropathy associated with high mortality among persons internally displaced by a volcanic eruption. *PLoS One* 8(9): e72566. Doi 10.1371/journal.pone.0072566.t003.

Salmang GA 2017. PNG fails to achieve MDG targets on malnutrition. *Post Courier* August 30, 2017. [www.postcourier.com.pg](http://www.postcourier.com.pg)

Sazawal S, Dhingra U, Dhingra P et al 2018. Efficacy of high zinc biofortified wheat in improvement of micronutrient status, and prevention of morbidity among preschool children and women – a double masked, randomized, controlled trial. *Nutrition Journal* 17: 86. Doi 10.1186/s12937-018-0391-5.

Schmidt E, Benson T, Holtemeyer B, Rosenbach G 2018. Papua New Guinea Household Survey on Food Systems: Initial Findings. *PNG Research Note 01: September 2018*. International Food Policy Research Institute (IFPRI), Washington DC, USA.

Shankar AH, Genton B, Semba RD et al 1999. Effect of vitamin A supplementation on morbidity due to *Plasmodium falciparum* in young children in Papua New Guinea: a randomised trial. *Lancet* 354: 203-209.

Shankar AH, Genton B, Baisor M et al 2000. The influence of zinc supplementation on morbidity due to *Plasmodium falciparum*: a randomized trial in preschool children in Papua New Guinea. *American Journal of Tropical Medicine and Hygeine* 62: 663-669.

Shinoda N, Sullivan KM, Tripp K et al 2013. Relationship between markers of inflammation and anaemia in children of Papua New Guinea. *Public Health Nutrition* 16: 289-295.

Sip J, Gendua P 2014. The status of maize in Papua New Guinea. In Prasanna BM et al (eds) *Book of extended summaries. 12th Asian Maize Conference and Expert Consultation on maize for Food, Feed, Nutrition and Environmental Security, 30th October to 1st November 2014.* CIMMYT, Mexico and APAARI. Bangkok, Thailand.

Sowei JW, Osilis P, Aliga W 1992. Sweet potato germplasm collection and evaluation in Papua New Guinea. *Discussion Paper 92/1* PNG Department of Agriculture and Livestock, Konedobu, PNG.

Temple VJ, Haindapa B, Turare R et al 2006. Status of iodine nutrition in pregnant and lactating women in national capital district, Papua New Guinea. *Asia Pacific Journal of Clinical Nutrition* 15: 533-537.

Temple VJ, Kaira C, Vince JD et al 2011. Vitamin A status of pre-school-age children aged 6 to 59 months in the National Capital District, Papua New Guinea. *Papua New Guinea Medical Journal* 54: 4-16.

Temple VJ, Etep D, Willie N et al 2015. Assessment of zinc status of women resident in the National Capital District, Papua New Guinea. *Papua new Guinea Medical Journal* 58: 11-21.

Temu PI, Saweri W 2001. Pp 395-406. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Trijatmiko KR, Duenas C, Tsarkirpaloglou N et al 2016. Biofortified indica rice attains iron and zinc dietary targets in the field. *Science Reports* 6: doi 10.1038/srep19792.

van Wijmeersch P 2001. Pp 674-682. In Bourke RM, Allen MG, Salisbury JG (eds) 2001. *Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99.* Australian Centre for International Agricultural Research (ACIAR). Canberra, Australia.

Wei Y, Shohag M, Yang X 2012, Biofortification and bioavailability of rice grain zinc as affected by different forms of foliar zinc fertilization. *PLoS One* 7(9) e45428.

Wera B, Yalu A, Ramakrishna A et al 2014. Genotypic variability estimates of agronomic traits for selection in a sweet potato (*Ipomoea batatas*) polycross population in Papua New Guinea. *Journal of Plant Breeding and Genetics* 2: 131-136.

Wirth JP, Woodruff BA, Engle-Stone R et al 2017. Predictors of anemia in women of reproductive age: biomarkers reflecting inflammation and nutritional determinants of anemia (BRINDA) project. *American Journal of Clinical Nutrition* 106: 416S-427S.

Zhang L, Zeng L, Gui G et al 2015. Zinc supplementation for infants and children with HIV infection. Pp 151-165. In Watson RR (ed) *Health of HIV infected people: food, nutrition and lifestyle without antiretroviral drugs.* Academic Press, doi 10.1016/B978-0-12-800767-9.00010-8.