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# Provitamin A Carotenoids in Baked Foods From Orange-Fleshed Sweet Potato Flour Are Substantially Bioaccessible and Contribute to Vitamin A Requirements

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**Abstract**

Vitamin A deficiency (VAD) remains a public health problem in developing countries. Consumption of orange-fleshed sweet potato (OFSP) varieties has been proven to be a valuable strategy for VAD alleviation. In this work, OFSP flour was incorporated into wheat flour at 15, 25, 35, and 50% (w/w) and used to prepare baked products. The bioaccessibility of provitamin A carotenoids of OFSP baking products was performed according to an *in vitro* digestion model. The contribution of OFSP-wheat composite baking products to vitamin A requirements was evaluated. Relatively high amounts (98.70±2.17-144.42±1.31 µg/g DM) of total carotenoids in OFSP flours was reported in Kakamega-7-Irene, Kabode, and Covington cultivars. The recovery of provitamin A carotenoid in baking products containing 15, 25, 35, and 50% OFSP flour was 1031.04±6.36-3364.21±10.22 µg/100 g for cupcakes and 1009.19±10.38-4640.72±13.43 µg/100 g for cookies, respectively. The *in vitro* bioaccessibility of provitamin A carotenoids of OFSP composite cupcake ranged from 12.53 to 27.21% while that of OFSP composite cookies was significantly different ($p < 0.05$) and ranged from 15.99 to 27.84%. The results also showed that cupcake and cookies containing 35% and 50% OFSP flours could be used to fight vitamin A deficiency in Côte d'Ivoire as they were found to meet 50 and more than 100% (161% for 100 g portion) of the recommended dietary allowance (RDA) of vitamin A for children aged 3-10 years. Finally, our results may support adoption of OFSP varieties in order to decrease the risk of vitamin A deficiency in Côte d'Ivoire.

**Keywords:** bioaccessibility, provitamin A carotenoids, OFSP flour, cupcakes, cookies

## 1. Introduction

Vitamin A deficiency (VAD) remains one of the major health problems among pre-school children, pregnant and lactating women in developing countries, especially in Africa and Southeast Asia (WHO, 2018). The World Health Organization reported that vitamin A deficiency affects about 250 million preschool children, and 19 million pregnant women in developing countries (WHO, 2017). VAD impairs children's growth, increases their vulnerability to disease, and contributes to poor immune function and maternal mortality (Christian & West, 1998). In Côte d'Ivoire, the prevalence of VAD is estimated to 57% for preschool-aged children and 19% for pregnant women (WHO, 2009).

It is well known that low dietary intake of vitamin A or β-carotene-rich foods, such as oil, fish, eggs, and milk, constitute a major contributing factor to VAD prevalence. Thus, to combat VAD in these populations, actions including food fortification, supplementation, and dietary diversity are often undertaken. However, compared to other food-based interventions, consumption of orange-fleshed sweet potato (OFSP) remains an affordable approach to meet the daily requirements of vitamin A in rural communities. Indeed, OFSP as a β-carotene-rich crop to partly replace white-fleshed cultivars in diets constitutes a suitable alternative to fight vitamin A deficiency as reported by some authors (Tumwegamire et al., 2004). Earlier studies documented the positive effect of OFSP supplementation on vitamin A status of population in low-income countries. According to Hotz et al. (2012), 100 g of boiled OFSP may supply the daily vitamin A needs for children under 5 years and vulnerable women in Mozambique. Research studies in South Africa also demonstrated the efficacy of OFSP as a bioavailable source of vitamin A (Jaarsveld et al., 2005), and community-level research in Mozambique indicated additional health benefit of OFSP in reducing diarrhoea prevalence children under 5 years of age (de Brauw & Jones, 2015; Low et al., 2007). In addition, diverse OFSP based products (including crisps, fries, porridge, juice, bread, porridge) are gaining importance in rural and urban communities of Eastern African countries (Neela & Fanta, 2019).

In spite of its nutritional value and importance in some African countries, orange-fleshed sweet potato remains underutilized in Côte d'Ivoire compared to traditional white and yellow cultivars (Konan et al., 2015). More recently, cultivation and consumption of biofortified β-carotene OFSP have been promoted in Côte d'Ivoire by Helen Keller International (HKI) in collaboration with the National Center of Agronomic Research (CNRA-Côte d'Ivoire) through the project entitled "Project Change". Results of this project showed that OFSP varieties were selected by farmers due to the higher yields (25 t/ha) than the local varieties and those best sensory attributes (Konan et al., 2017). However, successful adoption of OFSP varieties in households requires more information on how to use efficient cooking methods (Hotz et al., 2012). Indeed, commonly post-harvest processing (boiling, steaming, roasting, and frying) can affect provitamin A carotenoids content in OFSP, thus limiting their contribution to vitamin A requirements (Bechoff et al., 2011; Boy & Miloff, 2009; Haskell et al., 2004). Although some studies about the effect of different cooking methods on carotenoid retention were reported (Bechoff et al., 2009; Bengtsson et al, 2008), results on OFSP provitamin A bioaccessibility after processing stage are not well documented. Carotenoid bioaccessibility is defined as the fraction of carotenoids released from the food matrix and therefore becoming accessible for uptake by the intestinal mucosa (Brown et al., 2004; Reboul et al., 2006). Factors which can affect carotenoid bioaccessibility are the food matrix, the type of fiber and fat in the food, and homogenization caused by food processing (Bengtsson et al., 2009; Tumuhimbise et al., 2009; Veda et al., 2006). For sweet potatoes, the extent of carotenoid release from the food matrix depends on the variety and processing methods (Bengtsson et al., 2009; Tumuhimbise et al., 2009). Therefore, the primary objective of this study was to assess the impact of baking on the bioaccessibility of provitamin A carotenoids from OFSP blended products in order to evaluate their contribution to vitamin A requirements for different groups at risk.

## 2. Method

### *2.1 Chemicals*

Enzymes (α-Amylase, pepsin, and pancreatin) were purchased from Fluka Chemie (Wahlkreis Rheintal, Switzerland) and Merck KGaA (Darmstadt, Germany). β-carotene and butylated Hydroxytoluene (BHT) were purchased from Sigma-Aldrich. Other chemicals used in the experiments were of analytical grade.

### *2.2 OFSP Cultivars*

Orange-fleshed sweet potato (OFSP) cultivars: "Kakamega 7 Irene", "Kabode" and "Covington", were randomly selected from experimental field of National Center of Agronomic Research (CNRA-Côte d'Ivoire) located in the North and North-East regions of Côte d'Ivoire. Mature sweet potato roots were processed within two (2) days after harvest. Wheat flour and other ingredients were purchased from a shopping mall in Abidjan (Côte d'Ivoire).

### *2.3 Flour Preparation*

Orange-fleshed sweet potato roots were sorted, washed, peeled, sliced, and dried in a ventilated oven at 50°C for 18 h. Dehydrated sweet potato slices were milled into flour and sieved (250 µm). OFSP-wheat composite flours were produced from wheat flour and OFSP flour at different proportions of 100:0 (control), 85:15, 75:25, 65:35, and 50:50 (w/w), respectively. All flour samples including wheat flour (control) were vacuum-sealed in opaque zip-lock bags and stored at 4 °C before use.

### *2.4 Formulation of OFSP-Wheat Composite Cookies and Cupcake*

Briefly, cookies were prepared using flour (100 g), butter (50 g), sugar (25 g), whole milk powder (10 g), baking powder (1 g), water (25 mL), and a pinch of salt. All ingredients were mixed using an electric thresher. The resulting batter was baked in an oven at 180 °C for 5 min. The cookies were then cooled and used for further analyses. Cupcake samples were made using flour (100 g), butter (75 g), sugar (85 g), eggs (10 g), whole milk (15 mL), and baking powder (1 g). The resulting batter was baked in the same conditions as previously described.

### *2.5 Carotenoid Determination*

Total carotenoids of samples (OFSP flours and baking products) were extracted according to Howe and Tanumihardjo (2016) with slight modifications. Powdered samples (1 g) were mixed with 5 mL ethanol containing butylated hydroxytoluene (BHT 0.1%, w/v) and heated in a water bath at 85°C for 5 min. Then, 400 μL KOH in water (80%, w/v) was added for saponification, and the suspension was mixed using a vortex for 20 s and heated in a water bath at 85 °C for 5 min. The tubes containing the reaction mixture were placed in ice after introducing 3 mL distilled water. Carotenoids were extracted twice with 4 mL hexane and the combined extracts were used to quantify carotenoid content by using β-carotene as standard. Absorbance was read at 450 nm by using a spectrophotometer (Thermo Scientific$^{TM}$ Evolution 201 UV-Visible spectrophotometer, France).

### *2.6 In vitro Bioaccessibility of Provitamin A Carotenoids*

Determination of bioaccessibility of provitamin A carotenoids was carried out according to an *in vitro* digestion method (Delgado-Andrade et al., 2010) involving involved three phases (oral, gastric, and gastro-intestinal digestion). Shortly before use, 32.5 mg of lyophilized α-amylase was dissolved in 25 mL of 0.1 M $CaCl_2$ at pH 7, for oral phase. For gastric digestion, 0.4 g pepsin was dissolved in 2.5 mL of 0.1 M HCl. Finally, for gastro-intestinal digestion, 0.1 g of pancreatin was dissolved in 25 mL of 0.1 M $NaHCO_3$. One gram of each powdered baking sample was dissolved in 10 mL of ethanol containing 0.1% (w/v) BHT. For oral digestion, 250 μL of the alpha-amylase solution was added and the mixture was then incubated at 37 °C for 30 min in a shaking water bath (100-250 rpm). pH value was adjusted to 2 with 1M HCl, a pepsin solution was added at a volume of 300 μL, and samples were incubated at 37 °C for 1h in a shaking water bath (100-250 rpm) for the gastric digestion. For the gastrointestinal digestion phase, the pH of the digest was raised to 6 with 1M $NaHCO_3$ dropwise, and 2.5 mL of pancreatin solution was added. Then, the pH of mixture was adjusted to 7.5 with 1M $NaHCO_3$, and the samples were incubated at 37 °C for 1h in a shaking water bath (250 rpm). After the intestinal digestion, the digestive enzyme was inactivated by heat treatment for 4 min at 100 °C in a water bath. Afterward, the samples were cooled by immersion in an ice bath and centrifuged at 5000 g for 20 min. The supernatant of each sample was collected. Afterward, carotenoids were extracted two times by centrifugation (5000 g; 20 min) with 4 mL hexane. Absorbance of the combined extracts was measured at 450 nm using a spectrophotometer to quantify released provitamin A carotenoids.

### *2.7 Retinol Activity Equivalent (RAE) Determination*

The calculation of retinol activity equivalent (RAE) of OFSP-derived products after *in vitro* bioaccessibility was based on the bioconversion factor defined as 2 μg accessible β-carotene to 1 μg of retinol (2:1) (Institute of Medicine, 2011). The contribution of each type of OFSP-derived products to the vitamin A requirements for different groups of people was determined based on 100 g portion OFSP-derived products. Those groups were children (3-10 years), as well as pregnant and lactating women.

### *2.8 Statistical Analysis*

Values were reported as means±SD. One-way analysis of variance (ANOVA) was used to test differences in the effects based on substitution levels of wheat flour with OFSP flour. Statistica (Version 7.1; StatSoft Inc., France) was used for data analysis. Significant differences between means were determined using Duncan's least significant difference test (LSD) at 5% probability level ($p < 0.05$).

## 3. Results and Discussion

### *3.1 Provitamin A Carotenoid Content of OFSP Flours and OFSP-Derived Product*

Flour from dried orange-fleshed sweet potato (OFSP) was evaluated for moisture content ranging between 4.50±0.09% and 7.95±0.05% (Table 1). The low value of moisture content may be explained by the size of slices and drying method used (oven drying/50 °C during 18 h). Analysis of provitamin A carotenoid content of OFSP flour indicated values ($p < 0.05$) ranged from 98.70±2.17 to 144.42±1.31 μg/g DM (Table 1) with Covington having the highest content whereas the lowest content was found in Kabode cultivar. OFSP tubers contained respectively 309.36 μg/g DM (Covington), 309.56 μg/g DM (Kabode), and 309.36 μg/g DM of carotenoid for Kakamega-7-Irene cultivar (data no show). Thus, results in this study show that slow drying of OFSP slices results in loss of carotenoid estimated to 25.75%; 31.88%, and 32.81%, respectively for Covington, Kabode and Kakamega-7-Irene. However, provitamin A carotenoid contents obtained in OFSP flours studied were similar to that found for other orange-fleshed varieties (75.10-105.90 μg/g) and deep orange varieties (Gabriela et al., 2001). However, the values recorded in this study were lower compared to those (184-598 μg/g) of other varieties (*Jewel*, *Karotir Dar*, *Kabode,* and *Ejumula*) cultivated in Tanzania (Nicanuru et al., 2015). Variation in β-carotene content may be explained differences of varieties by growing conditions, stage of maturity, harvesting and post-harvest handling, processing and storage of OFSP, soil moisture and fertilization techniques (Rodriguez-Amaya, 2001; Ukom & Ojimelukwe, 2009).

Mixing wheat flour with OFSP flour resulted in increasing of carotenoid amount in composite cupcakes and cookies (Tables 2 and 3). The total carotenoid contents ranged from 1031.00±6.36-3364.00±10.22 µg/100 g and 1009.00±10.38-3364.00±10.22 µg/100 g for OFSP-Wheat composite cupcake and cookies, respectively. Similar trends were reported by Teferra et al. (2015) and Nzamwita et al. (2017) for OFSP composite bread prepared from maize (*Zea mays* L.) and OFSP flour (*Kitti*) and OFSP-wheat flour with different blending levels, respectively. The results of this study indicated that flours made from three OFSP cultivars contained suitable provitamin A carotenoid contents which could be interesting for production of vitamin A enriched confectionery and baked products.

Table 1. Moisture and provitamin A carotenoids contents of flours from OFSP cultivars

| OFSP cultivars | Moisture content (%) | Provitamin A carotenoids (µg/g DM) |
|---|---|---|
| Kakamega-7-Irene | 4.50±0.09$^{c}$ | 101.49±1.24$^{b}$ |
| Kabode | 5.15±0.20$^{b}$ | 98.70±2.17$^{c}$ |
| Covington | 7.95±0.05$^{a}$ | 144.42±1.31$^{a}$ |

*Note*. Data are presented as means of triplicate analyses±SD.

Means with the different superscript letters (a, b, c) in the same column indicate that means were significantly different ($p < 0.05$).

DM: dry matter.

Table 2. Total provitamin A contents (µg/100 g) of OFSP-Wheat composite cupcake

| OFSPF: WF (w/w) | OFSP cultivars | | |
|---|---|---|---|
| | Kakamega-7-Irene | Kabode | Covington |
| 0:100 | 0.00±0.00$^{e}$ | 0.00±0.00$^{e}$ | 0.00±0.00$^{e}$ |
| 15:85 | 1138.68±5.21$^{d}$ | 1031.04±6.36$^{d}$ | 1332.39±8.58$^{d}$ |
| 25:75 | 1421.51±4.45$^{c}$ | 1269.38±3.20$^{c}$ | 2155.29±10.56$^{c}$ |
| 35:65 | 1873.12±3.11$^{b}$ | 1486.68±8.76$^{b}$ | 2443.89±6.83$^{b}$ |
| 50:50 | 2589.91±3.52$^{a}$ | 1769.79±4.44$^{a}$ | 3364.21±10.22$^{a}$ |

*Note*. Data are presented as means of triplicate analyses±SD.

Table 3. Total provitamin A contents (µg/100 g) of OFSP-Wheat composite cookies

| OFSPF:WF (w/w) | OFSP cultivars | | |
|---|---|---|---|
| | Kakamega-7-Irene | Kabode | Covington |
| 0:100 | 0.00±0.00$^{e}$ | 0.00±0.00$^{e}$ | 0.00±0.00$^{e}$ |
| 15:85 | 1055.67±11.14$^{d}$ | 1009.19±10.38$^{d}$ | 2155.55±12.14$^{d}$ |
| 25:75 | 1512.91±6.15$^{c}$ | 1430.14±8.40$^{c}$ | 2814.36±9.13$^{c}$ |
| 35:65 | 1984.23±5.16$^{b}$ | 1648.68±6.33$^{b}$ | 3588.98±11.10$^{b}$ |
| 50:50 | 2555.27±8.28$^{a}$ | 2290.89±10.56$^{a}$ | 4640.72±13.43$^{a}$ |

*Note*. Data are presented as means of triplicate analyses±SD.

Means with the different superscript letters (a, b, c, d, e) in the same column indicate that means were significantly different ($p < 0.05$).

OFSPF: Orange-fleshed sweet potato flour; WF: wheat flour. w/w: weight/weight.

0:100, 15:85, 25:75, 35:65, and 50:50 represent wheat cupcake or cookies containing 0, 15, 25, 35 and 50% OFSP flour.

### *3.2 In vitro Bioaccessibility Provitamin A Carotenoid OFSP-Derived Products*

The first step before β-carotene conversion into vitamin A is the bioaccessibility. This biological phenomenon is an important feature to assess the role of food components such as vitamins in human health (Granado *et al.*, 2006). Data reported in this study showed that bioaccessibility of carotenoids was relatively higher and ranged from 12.53±0.24 to 27.21±1.53% and 15.99±0.36 to 27.84±0.63%, respectively for OFSP-Wheat cupcake and cookies (Figure 2). The calculated bioaccessibility of carotenoids from OFSP blended products in our experiment was in agreement with those (23.7-40.8%) reported by Bengtsson et al. (2009) and those (25.1 to 43.7%) obtained by Dhuique-Mayer et al. (2018). According to these authors, the efficiency of micellarization (*i.e.*, the relative amount of β-carotene transferred from the food matrix to micelles during digestion) was greater for products cooked with oil. Similarly greater bioaccessibility values of β-carotene were mentioned by Bechoff et al. (2011) in OFSP products cooked with oil such as *chapati* (73%) and *mandazi* (49%). In order to be accessible in the human body, carotenoids need to be released from the food matrix and dispersed into the lipid phase. Finally, in the next step, the carotenoids which are solubilized in the lipid emulsion droplets need to be incorporated into mixed micelles in the small intestine, together with free fatty acids, monoglycerides, and bile salts (Huo et al., 2007; Lemmens et al., 2014; Ornelas-Paz et al., 2008; Pullakhandam & Failla, 2007). In our study, the relatively high percentage of carotenoid bioaccessibility in OFSP-Wheat cupcake and cookies may be due to the incorporation of butter and egg yolk in the recipe promoting therefore the efficiency of micellarization. Indeed, Lei et al. (2012) mentioned that egg yolk is a natural phospholipids source acting as a surfactant to improve micelle formation, enhancing therefore the incorporation of β-carotene.

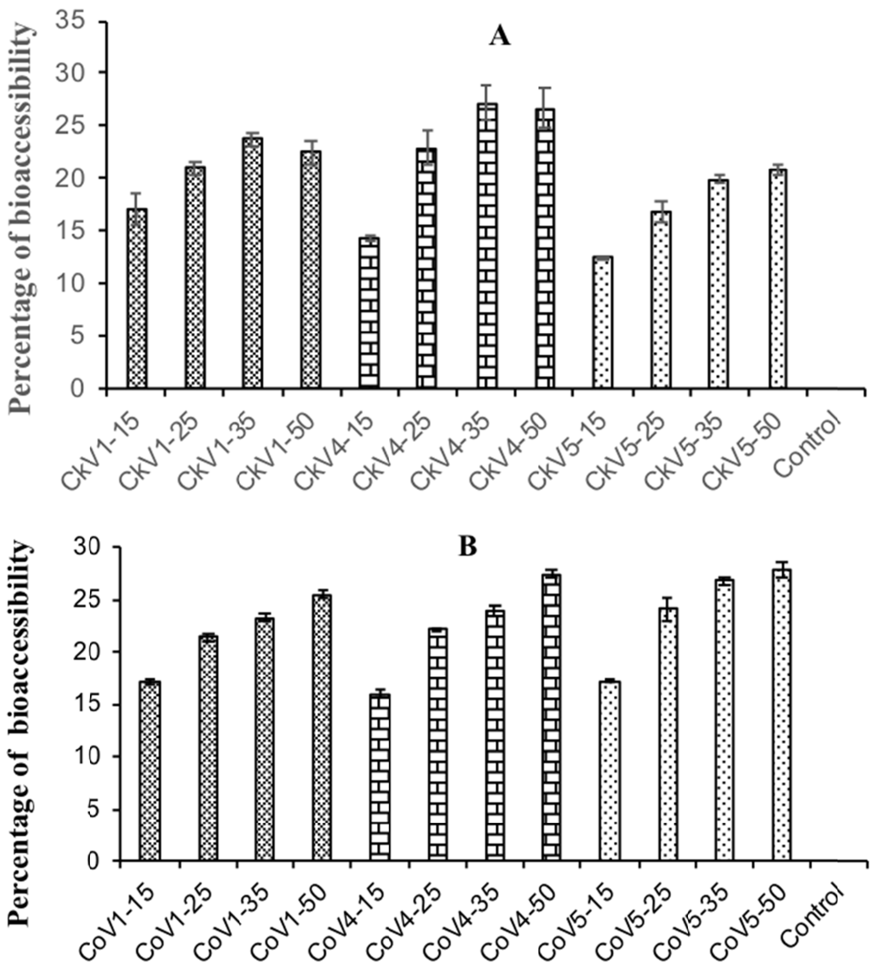


Figure 1. Bioaccessibility of carotenoids from OFSP-Wheat composite cupcake (A) and cookies (B) after *in vitro* digestion

*Note*. V1, V4, and V5 represent OFSP cultivars, Kakamega-7-Irene, Kabode, and Covington, respectively.

CkV1-15, CkV1-25, CkV1-35, and CkV1-50, represent wheat composite cookies containing different levels of OFSP flour.

CoV1-15, CoV1-25, CoV1-35, and CoV1-50, represent wheat composite cookies containing different levels of OFSP flour (15, 25, 35, and 50% of OFSP flour).

### *3.2 Evaluation of Vitamin A Activity in OFSP-Derived Products*

The bioaccessible carotenoid content in micellar fraction was between 148.39±0.03 to 697.37±0.13 µg/100 g for the OFSP-wheat cupcake (Table 3), whereas the amount varied between 159.53±0.03 and 1289.72±0.66 µg/100 g for the OFSP-wheat cookies (Table 4). Estimation of vitamin A activity in OFSP food products was calculated using the conversion factor adopted by (Institute of Medicine, 2011) assuming that one-sixth (1/6) of the total carotene content is absorbed into the mucosa and that one half (1/2) of absorbed β-carotene is converted to retinol. Hence, assuming a complete absorption of bioaccessible β-carotene, 100 g ready-to-eat portion of the OFSP blended products could provide from 74.19 to 348.69 and 79.78 to 644.88 µg of retinol equivalent activity (RAE), respectively for the OFSP blended cupcake and cookies. The contribution of cupcakes and cookies to the recommended dietary allowance (RDA) of vitamin A depends on the proportion of OFSP flour in the products (Tables 3 and 4). Hence, one portion (100 g) of cupcake and cookies made with 15 or 25% OFSP would cover 19-45% RDA for the cupcake, while cookies would contribute to 20-85% RDA of retinol for children aged between 3 and 10 years. On the other hand, the same portion of cupcake would provide a lower contribution to the daily requirements for pregnant and lactating mothers, varied from 9% to 23% for the cupcake and 10% to 42% for cookies. Furthermore, the same portion of cupcake or cookies supplemented with 35% or 50% OFSP flour would meet an amount of vitamin A more than half of the RDA for children aged 3-10 years. Based on the bioaccessible carotene level cupcake or cookies made with 35% and 50% could be important in addressing VAD in Côte d'Ivoire. More specifically, incorporating Convington cultivar into the diet of children aged 3-10 years may contribute to more than 100% of RDA. The same trend was recently mentioned by Nzamwita et al. (2017) indicating that 20-30% OFSP enriched bread (100 g portion) can reduce vitamin A disorders in children between the age of 3 and 10 years. Therefore, promotion of OSFP cultivars consumption could help alleviate vitamin A deficiency which remains a major health problem in developing countries, as Côte d'Ivoire.

In summary, the in vitro bioaccessibility of carotenoid from baking OFSP products was significantly higher, indicating the importance of OFSP flour-derived products as a significant source of provitamin A. This study suggested that promotion/marketing of products made with OFSP flour could contribute to alleviate vitamin A deficiency in Côte d'Ivoire. Therefore, growing OFSP as a home garden crop could be considered as a practical food-based approach to alleviate VAD in the community.

Table 4. Bioaccessible provitamin A after *in vitro* digestion of OFSP-Wheat composite cupcake and contribution (%) to the RDA of vitamin A of preschool children (3-10 years) and pregnant women

| OFSPF: WF (w/w) | OFSP cultivars | Accessible provitamin A carotenoids (µg/100 g) | Retinol Activity Equivalent RAE (µg/100 g) | Children 3-10 years (RDA=400 µg*) | Pregnant women (RDA = 800 µg*) |
|---|---|---|---|---|---|
| 0:100 | Control | 0.00±0.00 | 0.00 | 0.00 | 0.00 |
| 15:85 | Kakamega-7-Irene | 168.63±0.09[b] | 84.32 | 21.08 | 10.54 |
| | Kabode | 148.39±0.03[c] | 74.19 | 18.55 | 9.27 |
| | Covington | 194.14±0.04[a] | 97.07 | 24.27 | 12.13 |
| 25:75 | Kakamega-7-Irene | 299.05±0.36[B] | 149.53 | 37.38 | 18.69 |
| | Kabode | 277.79±0.46[C] | 138.90 | 34.72 | 17.36 |
| | Covington | 361.34±0.11[A] | 180.67 | 45.17 | 22.58 |
| 35:65 | Kakamega-7-Irene | 445.49±0.14[b] | 222.74 | 55.69 | 27.84 |
| | Kabode | 402.66±0.17[c] | 201.33 | 50.33 | 25.17 |
| | Covington | 487.46±0.27[a] | 243.73 | 60.93 | 30.47 |
| 50:50 | Kakamega-7-Irene | 675.31±0.08[b] | 337.65 | 84.41 | 42.21 |
| | Kabode | 471.78±0.35[c] | 235.89 | 58.97 | 29.49 |
| | Covington | 697.37±0.13[a] | 348.69 | 87.17 | 43.59 |

Table 5. Bioaccessible pro-vitamin A after *in vitro* digestion of OFSP-Wheat composite cookies and contribution (%) to the RDA of vitamin A of preschool children (3-10 years) and pregnant women

| OFSPF:WF (w/w) | OFSP cultivars | Accessible provitamin A carotenoids (μg/100 g) | Retinol Activity Equivalent RAE* (μg/100 g) | Children 3-10 years (RDA=400 μg**) | Pregnant women (RDA = 800 μg**) |
|---|---|---|---|---|---|
| 0:100 | Control | 0.00±0.00 | 0.00 | 0.00 | 0.00 |
| 15:85 | Kakamega-7-Irene | 180.79±0.16[b] | 90.39 | 22.60 | 11.30 |
| | Kabode | 159.53±0.03[c] | 79.76 | 19.94 | 9.97 |
| | Covington | 369.83±0.33[a] | 184.92 | 46.23 | 23.11 |
| 25:75 | Kakamega-7-Irene | 323.71±0.03[b] | 161.85 | 40.46 | 20.23 |
| | Kabode | 316.47±0.12[c] | 158.24 | 39.56 | 19.78 |
| | Covington | 678.13±0.16[a] | 339.06 | 84.77 | 42.38 |
| 35:65 | Kakamega-7-Irene | 461.13±0.42[b] | 230.57 | 57.64 | 28.82 |
| | Kabode | 412.06±0.77[c] | 206.03 | 51.51 | 24.69 |
| | Covington | 959.61±0.11[a] | 479.80 | 119.95 | 59.98 |
| 50:50 | Kakamega-7-Irene | 651.10±0.55[b] | 325.55 | 81.39 | 40.69 |
| | Kabode | 628.47±0.24[c] | 314.24 | 78.56 | 39.28 |
| | Covington | 1289.72±0.66[a] | 644.86 | 161.21 | 80.61 |

*Note*. ANOVA test was carried out with the different levels of OFSP flour substitution (*i.e.*, 15%, 25, 35, and 50% of OFSP flour). Thus, different subscripts (a, b, c, d …) in the same column and within the line of each ratio (OFSP: Wheat flour) were significantly different ($p < 0.05$).

OFSPF: orange-fleshed sweet potato flour. WF: wheat flour.

0:100, 15:85, 25:75, 35:65, and 50:50 represent wheat cupcake containing 0. 15. 25. 35 and 50% OFSP flour respectively.

* The retinol activity equivalency factors of 12:1 (Institute of Medicine, 2011).

** RDA: recommended dietary allowance.

## References

Bechoff, A., Poulaert, M., Tomlins, K. I., Westby, A., Menya, G., Young, S., & Dhuique-Mayer, C. (2011). Retention and bioaccessibility of β-carotene in blended foods containing orange-fleshed sweet potato flour. *Journal of Agricultural and Food Chemistry, 59*(18), 10373-10380. https://doi.org/10.1021/jf201205y

Bechoff, A., Tomlins, K. I., Dhuique-Mayer, C., Dufour, D., & Westby, A. (2009). *Understanding carotenoid losses in orange-fleshed sweet potato in drying and storage* (p. 8). 15th Triennal Symposium of the International Society for Tropical Root Crops (ISTRC). Tropical Roots and Tubers in a Changing Climate: A Convement Opportunity for the World, 2-6 November 2009, Lima, Peru. Retrieved from internal-pdf://op-52_a_bechoff-2924252160/OP-52_A_Bechoff.pdf

Bengtsson, A., Alminger, M. L., & Svanberg, U. (2009). In vitro bioaccessibility of β-carotene from heat-processed orange-fleshed sweet potato. *Journal of Agricultural and Food Chemistry, 57*(20), 9693-9898. https://doi.org/10.1021/jf901692r

Bengtsson, A., Namutebi, A., Alminger, M. L., & Svanberg, U. (2008). Effects of various traditional processing methods on the all-trans-β-carotene content of orange-fleshed sweet potato. *Journal of Food Composition and Analysis, 21*(2), 134-143. https://doi.org/10.1016/j.jfca.2007.09.006

Boy, E., & Miloff, A. (2009). Provitamin A Carotenoid Retention in Orange Sweet Potato: A Review of the Literature. *Methods, 3*, 27-33.

Brown, M. J., Ferruzzi, M. G., Nguyen, M. L., Cooper, D. A., Eldridge, A. L., Schwartz, S. J., & White, W. S. (2004). Carotenoid bioavailability is higher from salads ingested with full-fat than with fat-reduced salad dressings as measured with electrochemical detection. *American Journal of Clinical Nutrition, 80*(2), 396-403. https://doi.org/10.1093/ajcn/80.2.396

Christian, P., & West, K. P. (1998). Interactions between zinc and vitamin A: An update. *American Journal of Clinical Nutrition, 68*(2 Suppl.). https://doi.org/10.1093/ajcn/68.2.435S de Brauw, A., & Jones, K. M. (2015). Using Agriculture to Improve Child Health: Promoting orange sweet potatoes reduces diarrhea. *World Development, 74*, 15-24. https://doi.org/10.1016/j.worlddev.2015.04.007

Delgado-Andrade, C., Conde-Aguilera, J. A., Haro, A., Pastoriza de la Cueva, S., & Rufián-Henares, J. Á. (2010). A combined procedure to evaluate the global antioxidant response of bread. *Journal of Cereal Science, 52*(2), 239-246. https://doi.org/10.1016/j.jcs.2010.05.013

Dhuique-Mayer, C., Servent, A., Messan, C., Achir, N., Dornier, M., & Mendoza, Y. (2018). Bioaccessibility of Biofortified Sweet Potato Carotenoids in Baby Food: Impact of Manufacturing Process. *Frontiers in Nutrition, 5*(October), 1-9. https://doi.org/10.3389/fnut.2018.00098

Dibi, K. E. B., Essis, B. S., N'Zué, B., Kouakou, A. M., Zohouri, G. P., Assouan, A. B., & Van Mourik, T. (2017). Participatory selection of orange-fleshed sweetpotato varieties in north and north-east Côte d'Ivoire. *Open Agriculture, 2*(1), 83-90. https://doi.org/10.1515/opag-2017-0009

Dibi, Konan E. B., Essis, B. S., & Nzue, B. (2015). Techniques culturales de la patate douce. *Manuel de formation des agents de développement et des producteurs*.

Gabriela, B., Carpio, R., Sanchez, C., Paola, S., Eduardo, P., & Espinoza, J. (1991). A color chart to screen for high β-carotene in OFSP breeding. *International Society for Tropical Root Crops*, 47-52.

Granado, F., Olmedilla, B., Herrero, C., Pérez-Sacristán, B., Blanco, I., & Blázquez, S. (2006). Bioavailability of carotenoids and tocopherols from broccoli: *In vivo* and in vitro assessment. *Experimental Biology and Medicine, 231*(11), 1733-1738. https://doi.org/10.1177/153537020623101110

Haskell, M. I., Hassan, F., Fuchs, G. J., Haskell, M. J., Jamil, K. M., Peerson, J. M., & Brown, K. H. (2004). Daily consumption of Indian spinach (Basella alba) or sweet potatoes has a positive effect on total-body vitamin A stores in Bangladeshi men. *The American Journal of Clinical Nutrition, 80*(3), 705-714. https://doi.org/10.1093/ajcn/80.3.705

Hotz, C., Loechl, C., De Brauw, A., Eozenou, P., Gilligan, D., Moursi, M., ... Meenakshi, J. V. (2012). A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women. *British Journal of Nutrition, 108*(1), 163-176. https://doi.org/10.1017/S0007114511005174

Howe, J. A., & Tanumihardjo, S. A. (2016). Carotenoid-biofortified maize maintains adequate Vitamin A status in Mongolian Gerbils. *The Journal of Nutrition, 136*(10), 2562-2567. https://doi.org/10.1093/jn/136.10.2562

Huo, T., Ferruzzi, M. G., Schwartz, S. J., & Failla, M. L. (2007). Impact of fatty acyl composition and quantity of triglycerides on bioaccessibility of dietary carotenoids. *Journal of Agricultural and Food Chemistry, 55*(22), 8950-8957. https://doi.org/10.1021/jf071687a

Institute of Medicine. (2011). *Nutrients Summary (Dietary Reference Intake (RDIs): Vitamins)* (pp. 2-5). Retrieved from https://fnic.nal.usda.gov/sites/fnic.nal.usda.gov/files/uploads/DRI_Vitamins.pdf

Jaarsveld, P. J. Van, Faber, M., Tanumihardjo, S. A., Nestel, P., Lombard, C. J., & Benadé, A. J. S. (2005). β-Carotene-rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the. *American Journal of Clinical Nutrition, 81*(1), 1080-1087. https://doi.org/10.1093/ajcn/81.5.1080

Lei, L., Li, J., Hu, J., Liu, R., Fan, Y., Tang, L., & Deng, Z. (2012). Separation of phospholipids from hen egg yolk by short packed silica gel column chromatography. *Journal of Food Science, 77(*9), C948-953. https://doi.org/10.1111/j.1750-3841.2012.02850.x

Lemmens, L., Colle, I., Van Buggenhout, S., Palmero, P., Van Loey, A., & Hendrickx, M. (2014). Carotenoid bioaccessibility in fruit- and vegetable-based food products as affected by product (micro)structural characteristics and the presence of lipids: A review. *Trends in Food Science and Technology, 38*(2), 125-135. https://doi.org/10.1016/j.tifs.2014.05.005

Neela, S., & Fanta, S. W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. *Food Science and Nutrition, 7*(6), 1920-1945. https://doi.org/10.1002/fsn3.1063

Nicanuru, C., Laswai, H. S., & Sila, D. N. (2015). Effect of sun-drying on nutrient content of orange fleshed sweet potato tubers in Tanzania. *Sky Journal of Food Science, 4*(7), 91-101. Retrieved from http://skyjournals.org/sjfs/pdf/2015/Nov/Nicanuru et al pdf.pdf

Nzamwita, M., Duodu, K. G., & Minnaar, A. (2017). Stability of β-carotene during baking of orange-fleshed sweet potato-wheat composite bread and estimated contribution to vitamin A requirements. *Food Chemistry, 228*, 85-90. https://doi.org/10.1016/j.foodchem.2017.01.133

Ornelas-Paz, J. D. J., Failla, M. L., Yahia, E. M., & Gardea-Bejar, A. (2008). Impact of the stage of ripening and dietary fat on *in vitro* bioaccessibility of β-carotene in "Ataulfo" mango. *Journal of Agricultural and Food Chemistry, 56*(4), 1511-1516. https://doi.org/10.1021/jf072751r

Pullakhandam, R., & Failla, M. L. (2007). Micellarization and intestinal cell uptake of β-carotene and lutein from drumstick (*Moringa oleifera*) leaves. *Journal of Medicinal Food, 10*(2), 252-257. https://doi.org/10.1089/jmf.2006.250

Reboul, E., Richelle, M., Perrot, E., Desmoulins-Malezet, C., Pirisi, V., & Borel, P. (2006). Bioaccessibility of carotenoids and vitamin E from their main dietary sources. *Journal of Agricultural and Food Chemistry, 54*(23), 8749-8755. https://doi.org/10.1021/jf061818s

Rodriguez-Amaya, D. B. (2001). A Guide to Carotenoid Analysis in Foods. *Life Sciences*.

Teferra, T. F., Kurabachew, H., Tadesse, T. F., & Nigusse, G. (2015). Nutritional, Microbial and Sensory Properties of Flat-bread (kitta) Prepared from Blends of Maize (*Zea mays* L.) and Orange-fleshed Sweet Potato (*Ipomoea batatas* L.) Flours Fabrication of Iron and ascorbic acid Nanocomposite View project Nutritional, Micro. *International Journal of Food Science and Nutrition Engineering, 2015*(1), 33-39. https://doi.org/10.5923/j.food.20150501.05

Tumuhimbise, G. A., Namutebi, A., & Muyonga, J. H. (2009). Microstructure and In Vitro beta carotene bioaccessibility of heat processed orange-fleshed sweet potato. *Plant Foods for Human Nutrition, 64*(4), 312–318. https://doi.org/10.1007/s11130-009-0142-z

Tumwegamire, S., Kapinga, R., Zhang, D., Crissman, C., & Agili, S. (2005). Opportunities for promoting orange-fleshed sweet potato as a mechanism for combat vitamin-A deficiency in Sub-Saharan Africa. *African Crop Science Journal, 12*(3). https://doi.org/10.4314/acsj.v12i3.27884

Ukom, A. N., Ojimelukwe, P., & Okpara D. A. (2009). Nutrient composition of selected sweet potato (*Ipomea batatas* (L.) Lam) varieties as influenced by different levels of nitrogen fertilizer application. *Pakistan Journal of Nutrition, 8*(11), 1791-1795. https://doi.org/10.3923/pjn.2009.1791.1795

Veda, S., Kamath, A., Platel, K., Begum, K., & Srinivasan, K. (2006). Determination of bioaccessibility of β-carotene in vegetables by in vitro methods. *Molecular Nutrition and Food Research, 50*(11), 1047-1052. https://doi.org/10.1002/mnfr.200600076

WHO (World Health Organization). (2017). *10 facts on nutrition*. Retrieved May 10, 2020, from http://www.who.int/features/factfiles/nutrition/en

WHO (World Health Organization). (2018). *Micronutrient Deficiencies—Vitamin A Deficiency*. Retrieved May 10, 2020, from http://www.who.int/nutrition/topics/vad/en

WHO. (2009). World Health Organization (2009) *Global prevalence of vitamin A deficiency in populations at risk 1995-2005: WHO global database on vitamin A deficiency*. Geneva, Switzerland: WHO Press.