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Contribution of animal pollination to food nutrient production in Benin-West Africa

Hermann Cyr Toni^{1*} , Armand Avohou² and Bruno Agossou Djossa^{1,3}

Abstract

Background: Pollinators play a key role in human food production by improving the yield and quality of crops. Several studies assessed the economic value of pollination services delivered by animals through yield improvement. However, little is known about the contribution of animal pollinators to nutrient production. This study assessed the contribution of animal pollination to nutrient production in Benin. Food and Agriculture Organization data on crop production and United States Department of Agriculture crop composition data of 37 leading crops were used. These crops were categorized into five classes, depending on their degree of dependence on animal pollinators for fruit production.

Results: The study showed that more than half of the studied crops (56.75%) relies at different levels on animal pollination for fruit production. Minerals, namely fluoride (83.92%) and selenium (52.62%), were the most delivered by animal-pollinated crops. Roughly 50% of lipids outputs and 24% of proteins outputs were obtained from pollinator-dependent crops. Significant outputs of fat-soluble vitamins up to 65% were also attributed to animal pollination. A low contribution of animal pollination (up to 8%) was reported for water-soluble vitamins.

Conclusion: Animal-pollinated crops significantly contribute to the supply of nutrients and consequently to nutritional and food security in Benin. Conservation of pollinators should be considered as an important component of food security programs in the country.

Keywords: Nutrient supply, Biotic pollination, Food security, Benin

Background

Approximately 87% of main crops used in human diet worldwide depend on pollinators for fruit and seed production (Gallai et al., 2009; Klein et al., 2007). During flower visits, living organisms (insects, bats, birds, etc.) provide an important ecosystem service by transporting pollen grains to stigma (Dar et al., 2017). The yields of crops pollinated by living organisms are clearly enhanced since they induce production of larger and more fruits (Klein et al., 2007). Pollinators also improved fruit quality by improving their nutrient composition (Moses et al., 2005; Shar et al., 2012). The coupled effect of pollinators

on the yield and quality of crops increases the commercial value of crops and then producers' incomes (Garratt et al., 2014).

To understand the importance of pollination services delivered by animals, several studies assessed their economic value. Those studies revealed that animal pollination is ecosystem service of great economic value worldwide. The value of pollination services delivered by wild and managed pollinators worldwide amounted to €153 billion in 2005 (Gallai et al., 2009). Significant contributions of pollinators were also reported at the state level in some countries such as Australia (Gordon & Davis, 2003), Egypt (Brading et al., 2009) and Brazil (Giannini et al., 2015). In Benin (West Africa), the economic value of animal pollination in production of some important crops for the year 2010 was estimated to €152 million (Toni & Djossa, 2015). In addition to the

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economic value, other studies brought to light importance of animal pollinators to human by assessing their contribution to nutrient production. Few studies have been conducted on the contribution of pollinators to nutrient production surely because the first study of this kind was conducted recently (2011) and developed appropriate methodologies for assessing contribution of pollination to nutrient production (Eilers et al., 2011). It revealed that about 74% of lipids, 70% of vitamin A and other essential nutrients produced worldwide are present in animal-pollinated plants. The same methodology was used in China and found that over 80% of plant proteins and lipids, about 70% of vitamins A and E, and approximately 70% of vitamins B come from plants pollinated by animals (Wang and Ding 2012). The contribution of animal pollinators to food nutrient supply varies from one region to another depending on crops grown and the quantity produced within the regions (Eilers et al., 2011). This situation raises the necessity to assess the contribution of animal pollination to nutrient production in different regions, especially in Africa where few studies assessed the importance of pollination services (Rodger et al., 2004). This work focused on the contribution of animal pollinators to nutrient production in Benin will undoubtedly contribute to demonstrate the importance of pollinators to local communities, which have a low awareness on pollination services (Djossa et al., 2012).

Methods

Study area

The study was conducted in Benin, a tropical country located in West Africa. The country is situated between latitudes 6°30' and 12°30'N and longitudes 1° and 3°40'E. The country covers an area of 114,763 square kilometers with a population estimated to 11.49 million inhabitants in 2018. The annual rainfall varies between 900 and 1300 mm with four seasons (two rainy seasons and two dry seasons) in South-Benin and two seasons (one rainy season and one dry season) in the North. Four major groups of soils can be distinguished in the country: (1) ferrallitic soils covered by semi-deciduous forests, (2) ferruginous soils covered by dry forests, woodland, and savannah, (3) vertisol in the depression of Lama covered by semi-deciduous forests and (4) hydromorphic soils covered by swamp and riparian forests (Adomou, 2005). Agriculture is the main activity in rural areas, where the great part of crops is produced.

Data collection and analysis

We used FAOSTAT (Food and Agriculture Organization Corporate Statistical Database) crop production data on 37 leading crops produced in Benin from 2012 to 2016

to calculate the average annual production of each crop. Nutrient composition data for these raw crops, and the percentage of refuse (waste) were obtained from the United States Department of Agriculture (USDA) database (USDA, 2018). The total energy (in gigajoules GJ), macronutrients (carbohydrates, proteins, lipids and dietary fiber) and micronutrients (in tons) were used to determine the contribution of animal pollinators to human nutrition in Benin. Micronutrients used are calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, copper, manganese, selenium and fluoride. These micronutrients also include water-soluble vitamins (thiamine, riboflavin, niacin, vitamin B5, vitamin B6, vitamin B9 and vitamin C) and fat-soluble vitamins: vitamin E (including β -, γ - and δ -tocopherol); vitamin K; vitamin A; and carotenoids (including α - and β -carotene, β -cryptoxanthin, lycopene, lutein and zeaxanthin). These different nutrients were chosen because they constitute the main components of studied crops, but also because data were available on their quantity in crops. Crops used were categorized into the five following classes according to their dependence ratio on animal pollinators "pollinator dependency" (Klein et al., 2007): (1) crops for which the yield does not depend on pollinators (midpoint=0%), (2) crops depending lightly on pollinators; i.e., 0 to 10% of yield depends on pollinators (midpoint=5%); (3) crops depending modestly (10 to 40% of yield) on pollinators (midpoint=25%); (4) crops depending greatly (40 to 90% of yield) on pollinators (midpoint=65%); (5) crops for which pollinators are essential, i.e., more than 90% of yield depends on pollinators (midpoint=95%). Cereals do not depend on biotic pollinators (Gallai et al., 2009) and were classified in the first category. In addition, crops for which pollinators improve the seed quality, but do not have an effect on the edible parts were considered as pollinator independent in the frame of this work (Eilers et al., 2011).

Based on data collected on completely pollinator-independent crops, the proportion of each nutrient produced by pollinator-independent crops (NV_i) was calculated using the equation:

$$NV_i = \sum NV * Pr_i * (1 - (\% Rf_i/100)) \text{ (Eiler et al. 2011)}$$

The proportion of each nutrient produced by pollinator-dependent crops (NV_p) was calculated by applying the following equation to pollinator-dependent crops:

$$NV_p = \sum NV * Pr_p * (1 - (\% Rf_p/100)) \text{ (Eiler et al. 2011)}$$

This proportion is composed of proportions attributed to animal pollination (NV_{ap}) and the proportion of self- or wind pollination (NV_{sw}). These proportions were calculated by applying the following equations:

$$NV_{ap} = \sum NV_p * (\% Pd/100)$$

$$NV_{sw} = \sum NV_p * (1 - \% Pd)/100$$

With NV=amount of each nutritional component in crop production (in metric tons); Pr=average production of each crop from 2012 to 2016 (in metric tons); Rf=refuse fraction (pits, rind, seeds, shells, etc.); Pd=pollinator dependency (0%, 5%, 25%, 65% and 95%); *i*=pollinator independent; *p*=pollinator dependent; ap=animal pollination; sw=self- or wind pollination.

The different proportions were calculated and were used to draw graphs in an Excel sheet.

Results

The 37 leading crops used for this study were categorized into five classes depending on the levels of pollinator dependency (Table 1). More than half of the leading crops (56.75%) relies at different levels on animal pollination for fruit production.

Calculations showed that majority of the considered nutrients were obtained at different degrees from animal-pollinator-dependent crops in Benin. It was estimated that 55.07% of lipids and 24.36% of proteins outputs were obtained from pollinator-dependent crops (Table 2, Fig. 1). Animal pollinators contributed to production of 20% and 9% of these nutrients, respectively. However, energy is delivered mainly by pollinator-independent crops (85.54%) such as roots, tubers and cereal crops.

The bulk of minerals contained in the leading crops were obtained from pollination-independent crops (Table 1, Fig. 2). However, production of all studied mineral depends somewhat at different low levels on animal pollination. Fluoride (83.92%) and selenium (52.62%) outputs were the most delivered by pollination-dependent crops.

Animal pollinators contributed highly to the supply of fat-soluble vitamins (Table 2, Fig. 3) and less to the supply of water-soluble vitamins (Table 2, Fig. 4). The majority of all studied fat-soluble vitamins came from pollinator-dependent crops. In fact, 3 to 65% of the production of these vitamins was attributed to animal pollination alone. Lycopene and β -cryptoxanthin are almost delivered only by these crops. As for water-soluble vitamins, the vitamins B5 (8.24%) and B2 (5.29%) were the most delivered by pollinator-dependent crops.

Discussion

Results of this study showed that animal pollinators contribute significantly to production of several crops of economic and nutritional importance in Benin. From the 37 leading crops used for the study, results indicate that almost 57% ($n=21$) depends on pollinators for a good development of fruits. The majority of these crops depend lightly and modestly on pollinators for fruit production. Moreover, roots, tubers and other crops such as banana and cabbage are considered as pollinator independent in the frame of this study, because pollinators do not affect their edible parts, but rely on pollinators for improvement of the seed quality (Gallai et al., 2009; Norman et al., 2018). As reported in some parts of the world (Gallai et al., 2009; Klein et al., 2007), the bulk of main crops used in human diet in Benin depends on pollinators. This great proportion of animal-pollinated crops in Beninese diet may be as result of the fact that majority (94%) of tropical plants depends on animal pollinators (Ollerton et al., 2011). So, a great part of crops available to feed people in Benin which is located in the tropical region of Africa depends on different degrees on pollinators. Beninese people have a diversified diet made of several animal-pollinated crops such as fruits, legumes and spices (INSAE, 2017). This high dependence of Beninese populations on animal-pollinated crops may increase

Table 1 Crops used for this study classified by pollinator dependency categories

Pollinator dependency categories	Crops/commodities
No dependency (0%)	Banana (<i>Musa spp.</i>), carrot (<i>Daucus carota</i>), cassava (<i>Manihot esculenta</i>), cabbage (<i>Brassica oleracea</i>), date (<i>Phoenix dactylifera</i>), fonio (<i>Digitaria exilis</i>), lettuce (<i>Lactuca sativa</i>), maize (<i>Zea mays</i>), millet (<i>Pennisetum glaucum</i>), onion (<i>Allium cepa</i>), pineapple (<i>Ananas comosus</i>), Irish potato (<i>Solanum tuberosum</i>), rice (<i>Oryza sativa</i>), sorghum (<i>Sorghum spp.</i>), sweet potato (<i>Ipomoea batatas</i>), taro (<i>Colocasia esculenta</i>), yams (<i>Dioscorea spp.</i>)
Little dependence (5%)	Cowpea (<i>Vigna unguiculata</i>), pepper and Chillies (<i>Capsicum spp.</i>), peanut (<i>Arachis hypogaea</i>), beans (<i>Phaseolus spp.</i>) palm nuts (<i>Elaeis guineensis</i>), orange (<i>Citrus sinensis</i>), black pepper (<i>Piper nigrum</i>), tomato (<i>Solanum lycopersicum</i>)
Modest dependence (25%)	Coconut (<i>Cocos nucifera</i>), coffee (<i>Coffea arabica</i>), shea butter (<i>Vitellaria paradoxa</i>), okra (<i>Abelmoschus esculentus</i>), pigeon pea (<i>Cajanus cajan</i>), sesame (<i>Sesamum indicum</i>), soya (<i>Glycine max</i>)
Great dependence (65%)	Cashew nut (<i>Anacardium occidentale</i>), cucumber (<i>Cucumis sativus</i>), kola nut (<i>Cola nitida</i>), mango (<i>Mangifera indica</i>)
Full dependence (95%)	Watermelon (<i>Citrullus lanatus</i>)

Table 2 Amount and percentage of nutrients obtained from pollinator-independent crops and pollinator-dependent crops

Nutriments	Pollinator-independent crops		Pollinator-dependent crops			
	NV _i (t, GJ)	NV _i (%)	NV _{sw} (t, GJ)	NV _{sw} (%)	NV _{ap} (t, GJ)	NV _{ap} (%)
Energy	61,562,410.34	85.54	6,771,539.41	9.41	3,637,979.108	5.05
Macro-nutrients						
Proteins	274,304.1955	75.64	55,073.52123	15.19	33,252.56085	9.17
Lipids	142,315.9028	44.92	110,821.9622	34.98	63,650.03935	20.09
Carbohydrates	3,184,132.363	94.92	117,876.1511	3.51	52,669.17499	1.57
Dietary fiber	326,537.0804	87.49	37,708.0728	10.10	8998.810733	2.41
Minerals						
Calcium (Ca)	1422.679219	69.06	476.0856546	23.11	161.4187774	7.84
Iron (Fe)	79.57423276	68.22	23.98858995	20.57	13.08072026	11.21
Magnesium (Mg)	3217.221999	75.88	575.2351115	13.57	447.2507914	10.55
Phosphorus (P)	6563.742439	75.20	1228.664676	14.08	936.1122706	10.72
Potassium (K)	36,529.11334	86.69	4138.837233	9.82	1471.607013	3.49
Sodium (Na)	913.5972155	89.34	88.42264436	8.65	20.58565499	2.013
Zinc (Zn)	569.0419567	96.82	10.09656548	1.78	8.57173416	1.46
Copper (Cu)	12.98513393	66.05	3.470323984	17.65	3.205132701	16.30
Manganese(Mn)	27.23275928	77.93	4.802385347	13.74	2.910711687	8.33
Selenium (Se)	0.057453562	47.38	0.033959664	28.01	0.02983602	24.61
Fluoride (F)	0.001252067	16.08	0.005994522	77.01	0.000537761	6.91
Vitamins						
Vitamin C	1223.608214	92.87	81.64652573	6.20	12.27305766	0.93
Vitamin A	0.677011425	38.78	1.004215952	57.53	0.064358961	3.69
β—carotene	7.785685216	40.00	10.96946289	56.36	0.708737483	3.64
α—carotene	0.359305899	27.10	0.914723374	69.00	0.051620779	3.89
β—cryptoxanthin	0.000347096	0.05	0.716274363	93.49	0.049514306	6.46
Lycopene	0.000101068	0.0013	6.656952534	87.13	0.982953451	12.87
Lutein + zeaxanthin	0.373252089	8.05	3.99664064	86.19	0.267287615	5.76
Vitamin E						
α—tocopherol	49.86116787	76.50	13.27713967	20.37	2.036747613	3.13
β—tocopherol	0.00528793	5.98	0.045362643	51.29	0.037793069	42.73
γ—tocopherol	0.082811187	0.81	3.813998521	37.19	6.358970483	62.00
δ—tocopherol	0.005040218	0.76	0.230311368	34.73	0.427721112	64.51
Vitamin B						
Thiamin (B1)	13.26146844	85.81	1.375492996	8.90	0.817230966	5.29
Riboflavin (B2)	4.430365606	68.17	1.695706361	26.09	0.372639018	5.73
Niacine (B3)	111.8093498	89.49	10.6843231	8.55	2.440947295	1.95
Pantothenic Acid(B5)	13.10753876	78.00	2.311338656	13.75	1.384777007	8.24
Vitamin B6	16.21025319	88.10	1.490304119	8.10	0.698689559	3.80
Folate	B9	2.197313018	76.58	0.516330151	17.99	0.155535108
Vitamin K	0.156033519	40.49	0.16674351	43.27	0.062553479	16.23

with human population growth leading to increase production of several crops in the future. For example, the last ten years, production of several pollinator-dependent crops increased (Fig. 5) surely to meet the demand of the population which grew from roughly 8 million people in 2007 to 11 million people in 2017 (INSAE, 2019). The contribution of pollinators could be more significant than

estimated in this study because Tchuenguem et al. (2002) showed that some tropical Gramineae could benefit from wild bee visits that induce the release of pollen grains.

Pollinators ensure pollen grain dispersal which is a key step of fruit formation. The contact of pollen grains and stigma leads firstly to fertilization and then to seed formation, and auxins synthesized in seeds control cell

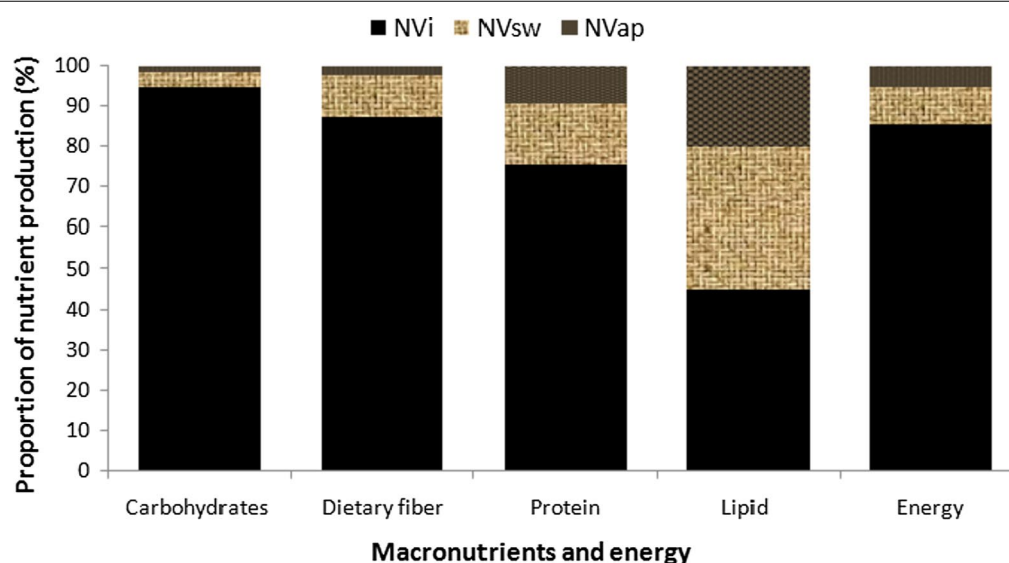


Fig. 1 Proportion of macronutrients and energy attributed to pollinator-independent crops, self- or wind pollination and animal pollination

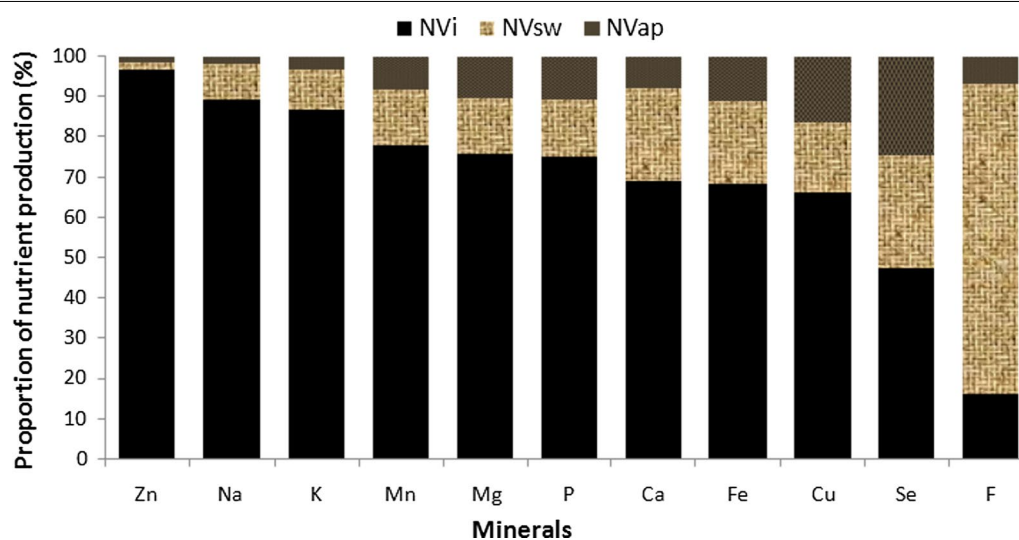


Fig. 2 Proportion of minerals attributed to pollinator-independent crops, self- or wind pollination and animal pollination. Zn = zinc, Na = sodium, K = potassium, Mn = manganese, Mg = magnesium, P = phosphorus, Ca = calcium, Fe = iron, Cu = copper, Se = selenium, F = fluoride

division and consequently fruit growth (Kumar et al., 2014). The abnormal development of fruit owing to pollination deficit could then affect the fruit quality (Junqueira & Augusto, 2017). Animal-pollinated crops consumed in Benin delivered a significant proportion of lipids and several micronutrients required for human health. More than 50% of lipid outputs were obtained from pollinator-dependent crops, with almost 20% attributed to animal pollination. Lipids from fruits and vegetables are a good source of energy and play key roles as cofactors, electron carriers, light-absorbing pigments, hydrophobic and

anchors for proteins (Baeza-Jiménez et al., 2017). In addition, bioactive compounds of plant fats such as stearidonic acid and gamma-linolenic acid inhibit the growth of cancer cells and contribute to treatment of some diseases such viral infections, osteoporosis and alcoholism (Baeza-Jiménez et al., 2017).

Animal-pollinated crops were also the main source of fat-soluble vitamins outputs in Benin. They delivered 57.53% of vitamin A, 56.36–93.49% of carotenoids and 43.27% of vitamin K. Pollinators have then a key role in production of vitamin A which improves child growth

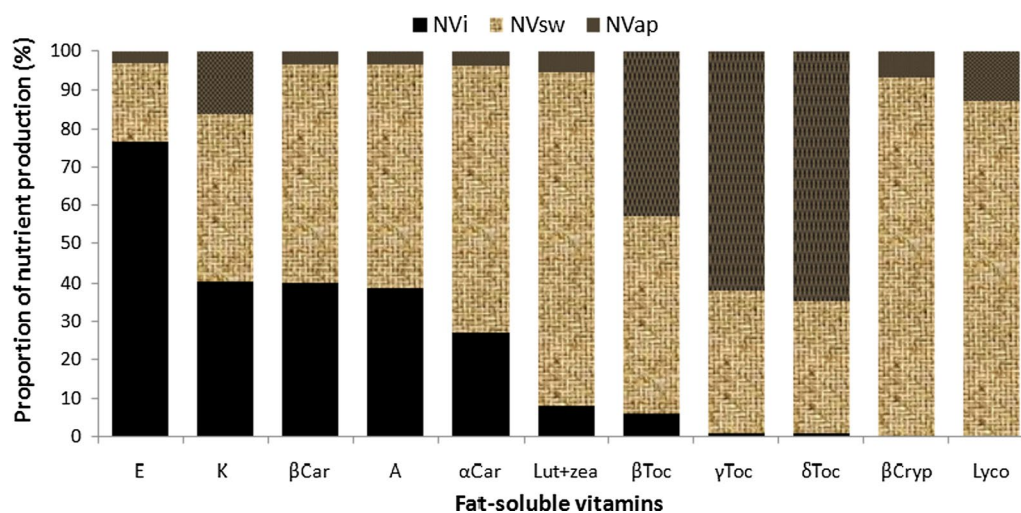


Fig. 3 Proportion of fat-soluble vitamins in national crop production attributed to pollinator-independent crops, self- or wind pollination and animal pollination. E = vitamin E, K = vitamin K, βCar = β-carotene, A = vitamin A, αCar = α-carotene, lut + zea = Lutein + zeaxanthin, βToc = β-tocopherol, γToc = γ-tocopherol, δToc = δ-tocopherol, βCryp = β-cryptoxanthin, Lyco = lycopene

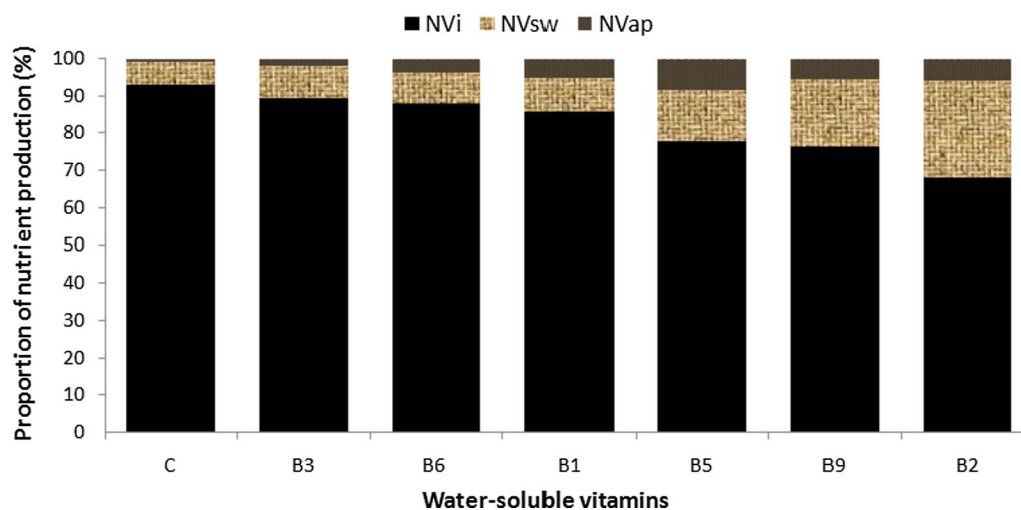


Fig. 4 Proportion of water-soluble vitamins in national crop production attributed to pollinator-independent crops, self- or wind pollination and animal pollination. C = vitamin C, B3 = niacin, B6 = vitamin B6, B1 = thiamine, B5 = pantothenic acid, B9 = folate, B2 = riboflavin

and reduce child mortality (Ramakrishnan & Martorell, 1998). It was also demonstrated that vitamin A and carotenoids reduce the risks of getting cancers (Leoncini et al., 2015). Vitamin K is necessary for bone metabolism, blood clotting and reduce the risks of peripheral arterial disease (Visser et al., 2016). Considering the roles of these nutrients, animal pollinators can contribute to prevent vitamin A deficiency reported in Benin as well as cancer risks in the country (INSAE, 2017). Additionally, animal-pollinated crops are source of water-soluble vitamins and minerals like selenium, calcium, iron and copper which also play several functions in the body such

as formation of thyroid hormones and nervous system development (Kennedy, 2016; Mehdi et al., 2013). Consequently, pollinators contribute to reduction of several diseases related to deficit of these nutrients such as iron deficiency, considered as the main cause of the high anemia prevalence in Benin (INSAE & ICF, 2018; Yessoufou et al., 2015). Results of this study corroborate those of Wang and Ding (2012) and Eilers et al. (2011) who showed that animal-pollinated crops contribute significantly to the production of lipids, vitamins, carotenoids and other minerals necessary to body nutrition. In fact, Wang and Ding (2012) found that pollinator-dependent

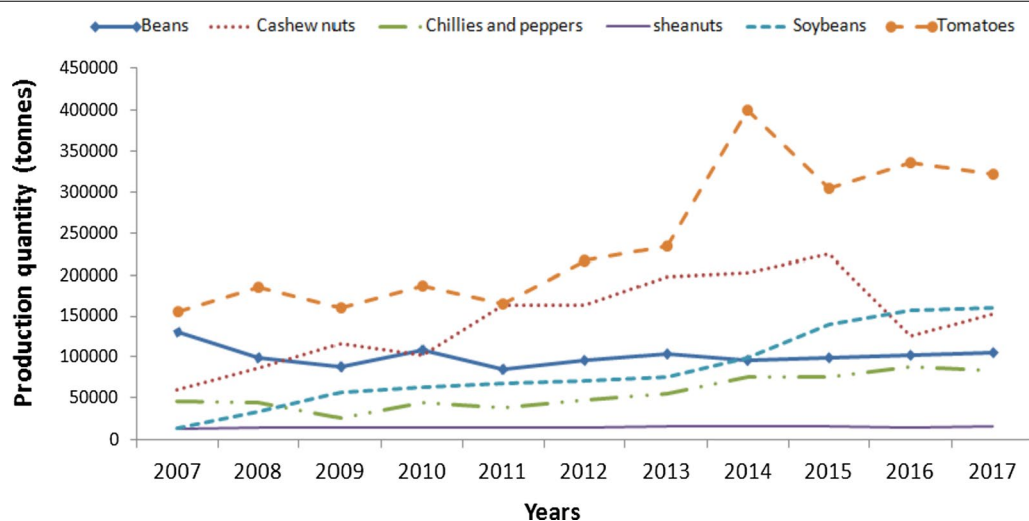


Fig. 5 Trend of increased production of some pollinator-dependent crops (2007–2017). Source: FAOSTAT data

plants are the source of more than 80% of macronutrients such as protein and dietary fiber and micronutrients such as zinc, selenium, calcium, phosphorus, potassium, copper, vitamin B1, vitamin B6 and vitamin C in China.

Most of these crops rely on insect pollinators to set fruit or seed to some degree. Pollinator-dependent plants yielded more than 80% of the protein, fat, zinc, selenium, calcium, phosphorus, potassium, copper, vitamin B1 and vitamin B5, over 90% of the dietary fiber, vitamin B6 and vitamin C, almost the entire quantity of alpha-carotene and beta-tocopherol, and the full amount of beta-cryptoxanthin and lycopene.

Despite the significant contribution of pollinator-dependent crops to nutrient outputs in Benin, several processing techniques used by local people result in nutrient loss (Vodouhè et al., 2012). Furthermore, efforts should be done to increase fruit and vegetable intakes in the country, which were reported to 135.95 g per person per day and 156.99 g per person per day respectively in 2013 (<https://ourworldindata.org/diet-compositions>). These intakes were far below the 400 g of fruits and vegetable recommended by the World Health Organization (2015), surely due to the low consumption of fruits by the majority of households (Darfour-Oduro et al., 2018; PAM & INSAE, 2014). A particular focus may be put on illiterate persons and in urban areas, where people eat less fruits than in rural areas (Agueh et al., 2016; FAO, 2011).

This study gives an overall outlook of the importance of animal pollination in human nutrition in Benin. However, the proportion of animal-pollinated crops would be more significant if this study took into account neglected, or minor crops (wild fruits) such as

Vitex doniana, *Parkia biglobosa*, *Irvengia gabonensis*, *Adansonia digitata* and *Blighia sapida*, which are used by local people, mainly in rural communities. Unfortunately, data required such as the pollination dependence degree and the national production were not available for several of these crops. In addition, the pollination dependency of crops used was mainly obtained from studies conducted in Europe. This may underestimate or overestimate the importance of animal pollinators, owing to variations obtained for this parameter, depending on the regions/habitats and crop varieties (Klein et al., 2007; Woodcock, 2012). Despite these limitations of this study, it has the merit of bringing out an estimation of the contribution of animal pollination to nutrient supply in Benin. This study also confirms the gap of data in pollination ecology of several indigenous crops of socio-economic importance in Benin like in several African countries (Rodger et al., 2004). The progressive intensification of agriculture in the country characterized by the increase in pesticides importations (FAOSTAT, 2018) combined with destruction of natural habitats for several purposes should draw attention of all actors of the agricultural sector on pollinator conservation. Indeed, it was demonstrated that the use of pesticides reduces bee species richness and abundance in farms (Kovács-Hostyánszki et al., 2011). Pesticides can also harm pollinators by direct intoxication during sprays (Pilatic, 2012) and indirect intoxication via indirect contacts with treated plants (Cresswell, 2011). Several agricultural practices related to intensive agriculture disturb natural habitats of pollinators (Bailey et al., 2014).

Conclusion

Results of this study reinforce knowledge on the importance of pollination services in Benin by showing the significance of pollinators in nutrient supply and consequently for nutritional and food security. Animal-pollinated crops deliver large quantities of macronutrients, minerals and vitamins which promote a good health. A decline of pollinators in Benin will definitely result in a decrease in nutrient inputs essential for food security. The development of conservation strategies of pollinators should also be taken into account in food security and nutrition policies and strategies. Further studies may be conducted to assess effect of animal pollination on nutrient composition of indigenous fruit species.

Abbreviations

FAOSTAT: Food and Agriculture Organization Corporate Statistical Database; NV: Amount of each nutritional component in crop production (in metric tons); NV_{ap}: The proportions of nutrients attributed to animal pollination; NV_i: The proportion of each nutrient produced by pollinator-independent crops; NV_p: The proportion of each nutrient produced by pollinator-dependent crops; NV_{sw}: The proportion of self- or wind pollination; Pd: Pollinator dependency; Pr: Average production of each crop; Rf: Refuse fraction; USDA: United States Department of Agriculture.

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Authors' contributions

HCT conceived the study and contributed to data analysis and manuscript writing. AA contributed to data collection, analysis and manuscript writing. BAD contributed to manuscript reviewing. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed for this study are included in the paper.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

We declare that there are no competing interests.

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References

- Adomou, C. A. (2005). Vegetation patterns and environmental gradients in Benin. Implications for biogeography and conservation. Ph.D. Thesis, Wageningen University, Wageningen, 133p.
- Agueh, V., Sossa, J. C., Gbessinon, M., Adomahoun, D., Degbey, C. C., Paraïso, M. N., Azandjè, C. S., Sopoh, G., Ahanhanzo-Glèlè, Y., Metonnou, C., & Ouédraogo, L. (2016). Facteurs associés à la consommation de fruits et légumes chez les personnes âgées de 18 ans et plus à Cotonou au Bénin en 2014. *Cahiers Du CBRST*, 10, 43–59.
- Baeza-Jiménez, R., López-Martínez, L. X., García-Varela, R., & García, H. S. (2017). Lipids in fruits and vegetables: Chemistry and biological activities. In E. M. Yahia (Ed.), *Fruit and vegetable phytochemicals: chemistry and human health* (2nd ed., pp. 423–450). Hoboken: Wiley. <https://doi.org/10.1002/9781119158042>
- Bailey, S., Requier, F., Nussillard, B., Roberts, S., Potts, S., & Bouget, C. (2014). Distance from forest edge affects bee pollinators in oilseed rape fields. *Ecology and Evolution*, 4(4), 370–380.
- Brading, P., El-Gabbas, A., Zalat, S., & Gilbert, F. (2009). Biodiversity economics: The value of pollination services to Egypt. *Egyptian Journal of Biology*, 11, 46–51.
- Cresswell, J. E. (2011). A meta-analysis of experiments testing the effects of a neonicotinoid insecticide (imidacloprid) on honey bees. *Ecotoxicology*, 20, 149–157.
- Dar, S. A., Hassan, G. I., Padder, B. A., Wani, A. R., & Parey, S. H. (2017). Pollination and evolution of plant and insect interaction. *Journal of Pharmacognosy and Phytochemistry*, 6(3), 304–311.
- Darfour-Ouduro, S. A., Buchner, D. M., Andrade, J. E., & Grigsby-Toussaint, D. S. (2018). A comparative study of fruit and vegetable consumption and physical activity among adolescents in 49 Low-and-Middle-Income Countries. *Scientific Reports*, 8(1), 1623. <https://doi.org/10.1038/s41598-018-19956-0>
- Djossa, B., Toni, H., Dossa, K., Azonahoun, P., & Sinsin, B. (2012). Local perception of ecosystem services provided by bats and bees and their conservation in Benin, West Africa. *International Journal of Biological and Chemical Sciences*, 6, 2034–2042.
- Eilers, E. J., Kremen, C., Greenleaf, S. S., Garber, A. K., & Klein, A. M. (2011). Contribution of pollinator-mediated crops to nutrients in the human food supply. *PLoS ONE*, 6(6), e21363.
- FAO Food and Agriculture Organisation of the United States (2010). Profil nutritionnel du Bénin. Retrieved December 30, 2018, from http://www.fao.org/ag/agn/nutrition/ben_fr.stm.
- FAO Food and Agriculture Organisation of the United States (2011). Profil Nutritionnel du Bénin. Retrieved January 10, 2020, from <http://www.fao.org/3/a-bc623f.pdf>.
- FAOSTAT Food and Agriculture Organization Corporate Statistical Database (2018). Production database. Retrieved December 15, 2018, from <http://www.fao.org/faostat/fr/#data/QC>.
- Gallai, N., Salles, J. M., Settele, J., & Vaissiere, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, 68, 810–821.
- Garratt, M. P. D., Breeze, T. D., Jenner, N., Polce, C., Biesmeijer, J. C., & Potts, S. G. (2014). Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems and Environment*, 184, 34–40.
- Giannini, T. C., Cordeiro, G. D., Freitas, B. M., Saraiva, A. M., & Imperatriz-Fonseca, V. L. (2015). The dependence of crops for pollinators and the economic value of pollination in Brazil. *Journal of Economic Entomology*, 108(3), 849–857. <https://doi.org/10.1093/jee/tov093>
- Gordon, J., & Davis, L. (2003). *Valuing honeybee pollination*. Rural Industries Research and Development Corporation Paper 03/077, Canberra, ACT, Australia.
- INSAE Institut National de la Statistique et de l'Analyse Economique (2017). Analyse Globale de la Vulnérabilité et la Sécurité Alimentaire (AGVSA). 146p.
- INSAE Institut National de la Statistique et de l'Analyse Economique (2019). Retrieved January 10, 2020, from <https://www.insae-bj.org/images/docs/insae-statistiques/demographiques/mortalite/Mortalite.pdf>.
- INSAE Institut National de la Statistique et de l'Analyse Économique & ICF (2018). *Enquête démographique et de santé au Bénin, 2017–2018: Indicateurs clés*. Cotonou, Bénin et Rockville, Maryland, USA.

- Junqueira, C. N., & Augusto, S. C. (2017). Bigger and sweeter passion fruits: Effect of pollinator enhancement on fruit production and quality. *Apidologie*, 48(2), 131–140.
- Kennedy, D. O. (2016). B Vitamins and the brain: Mechanisms, dose and efficacy- A review. *Nutrients*, 8(2), 68. <https://doi.org/10.3390/nu8020068>
- Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society of London: Series B Biological Sciences*, 274, 303–313. <https://doi.org/10.1098/rspb.2006.3721>
- Kovács-Hostyánszki, A., Batáry, P., & Báldi, A. (2011). Local and landscape effects on bee communities of Hungarian winter cereal fields. *Agricultural and Forest Entomology*, 13, 59–66.
- Kumar, R., Khurana, A., & Sharma, A. K. (2014). Role of plant hormones and their interplay in development and ripening of fleshy fruits. *Journal of Experimental Botany*, 65(16), 4561–4575. <https://doi.org/10.1093/jxb/eru277>
- Leoncini, E., Nedovic, D., Panic, N., Pastorino, R., Edefonti, V., & Boccia, S. (2015). Carotenoid intake from natural sources and head and neck cancer: A systematic review and meta-analysis of epidemiological studies. *Cancer Epidemiology, Biomarkers & Prevention*, 24(7), 1003–1011. <https://doi.org/10.1158/1055-9965.EPI-15-0053>
- Mehdi, Y., Hornick, J. L., Istasse, L., & Dufrasne, I. (2013). Selenium in the environment, metabolism and involvement in body functions. *Molecules*, 18(3), 3292–3311.
- Moses, T. N., Witlmann, D., & Schindler, M. (2005). Effect of bee pollination on seed set and nutrition on okra (*Abelmoschus esculentus*) in Cameroon. Deutscher Tropentag conference, Stuttgart-Hohenheim, October 11–13, 2005. Retrieved March 4, 2018, from http://www.tropentag.de/2005/abstracts/links/Njoya_20xLtV08.php.
- Norman, P. E., Asfaw, A., Tongoona, P. B., Danquah, A., Danquah, E. Y., De Koeber, D., & Asiedu, R. (2018). Pollination success in some white yam genotypes under polycross and nested mating designs. *International Journal of Biological Sciences and Applications*, 5(2), 19–28.
- Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, 120(3), 321–326.
- PAM Programme Alimentaire Mondial & INSAE (2014). Analyse Globale de la Vulnérabilité et de la Sécurité Alimentaire (AGVSA). Retrieved January 30, 2019, from <https://www.insae-bj.org/images/docs/insae-statistiques/enquetes-recensements/autres-Enquetes/AGVSA/Benin-AGVSA-Rapport-2013.pdf>.
- Pilatic, H. (2012). *Pesticides and honey bees: State of the Science*. Pesticide Action Network North America (PANNA). 27p.
- Ramakrishnan, U., & Martorell, R. (1998). The role of vitamin A in reducing child mortality and morbidity and improving growth. *Salud Pública De México*, 40(2), 189–198.
- Rodger, J. G., Balkwill, K., & Gemmill, B. (2004). African pollination studies: Where are the gaps? *International Journal of Tropical Insect Science*, 24(1), 5–28.
- Shar, G. Q., Memon, A. H., Makhija, P. M., Shamroz, B., & Jatwi, W. B. (2012). Physico-chemical characteristics of pollinated and non pollinated date fruit of district Khairpur, Sindh, Pakistan. *Pakistan Journal of Analytical & Environmental Chemistry*, 13(2), 107–117.
- Tchuenguem, F., Messi, J., & Pauly, A. (2002). L'activité de butinage des Apoïdes sauvages (Hymenoptera Apoïdea) sur les fleurs de maïs à Yaoundé (Cameroun) et réflexions sur la pollinisation des graminées tropicales. *Biotechnologie, Agronomie, Société Et Environnement*, 6(2), 87–98.
- Toni, H., & Djossa, B. A. (2015). Economic value of pollination services on crops in Benin, West Africa. *International Journal of Biological and Chemical Sciences*, 9(1), 225–233.
- USDA United States Department of Agriculture (2018). Retrieved November 12, 2018, from <https://ndb.nal.usda.gov>.
- Vissers, L. E. T., Dalmeijer, G. W., Boer, J. M. A., Verschuren, W. M. M., van der Schouw, Y. T., & Beulens, J. W. J. (2016). The relationship between vitamin K and peripheral arterial disease. *Atherosclerosis*, 252, 15–20.
- Vodouhè, S., Dovoédo, A., Anihouvi, V. B., Tossou, R. C., & Soumanou Mohamed, M. (2012). Influence du mode de cuisson sur la valeur nutritionnelle de *Solanum macrocarpum*, *Amaranthus hybridus* et *Ocimum gratissimum*, trois légumes feuilles traditionnels acclimatés au Bénin. *International Journal of Biological and Chemical Sciences*, 6(5), 1926–1937.
- Wang, X. H., & Ding, S. Y. (2012). Pollinator-dependent production of food nutrients by fruits and vegetables in China. *African Journal of Agricultural Research*, 7(46), 6136–6142.
- Woodcock, T. (2012). *Pollination in the agricultural landscape best management practices for crop pollination*. Canadian Pollination Initiative (NSERC-CAN-POLIN), University of Guelph. 113p
- World Health Organization (2015). Healthy diet. Retrieved September 10, 2019, from https://www.who.int/elena/healthy_diet_fact_sheet_394.pdf?ua=1.
- Yessoufou, A. G., Béhanzin, J., Ahokpè, M., Djinti, S. A., Bossou, R., & Sezan, A. (2015). Prévalence de l'anémie chez les enfants malnutris de 6 à 59 mois hospitalisés au CHD/Zou-Collines dans le plateau d'Abomey (Centre du Bénin). *International Journal of Biological and Chemical Sciences*, 9(1), 82–90.

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