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Leafy Vegetables under Shade? Performance, Consumer Acceptance, and Nutritional Contribution of Cowpea (*Vigna unguiculata* (L.) Walp.) Leaves in the Yayu Coffee Forest Biosphere Reserve in Southwest Ethiopia

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Abstract: In rural Ethiopia, people consume mainly cereals and pulses. Integrating vegetables into the multi-storey cropping system of the Yayu Coffee Forest Biosphere Reserve could improve nutritional health while reducing pressure on natural habitats in the biodiversity hotspot. The aim of the study was to assess the performance of cowpea under shade and its consumer acceptance as leafy vegetables. Trials compared continuous harvesting with uprooting, and food preference was tested. A baseline survey was conducted in four villages and revealed that cropping of vegetables in coffee plantations would be adoptable by 17% of farmers. The cumulatively harvested mean leaf yield (18.15 t ha^{-1}) was significantly higher than the leaf yield of the uprooted cowpea (6.56 t ha^{-1}). As many as 41% (52%) of participants liked cowpea dishes (very much). Based on the trial yields and the RDA, a 25 m^2 cowpea plot could produce sufficient vitamin A for 2.1–4.6 adults, iron for 0.8–1.7, and vitamin C for 1.3–2.9 adults during six months. Cowpea was successfully cultivated below coffee, yielded most when repeatedly harvested and showed a high acceptance among consumers. The consumption of cowpea leaves from coffee forests could contribute to a balanced diet and improved nutrition.

Keywords: cooking demonstrations; cowpea leaves; harvesting regime; nutritional yield; vegetable consumption

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1. Introduction

Worldwide, vegetable production and consumption is insufficient which can also be described as a dietary gap between current dietary patterns and recommended food intake [1]. The World Health Organization suggests a minimum of 400 g of vegetables and fruits to be consumed per person and day [2] while more recent recommendations are higher, for example 300 g of vegetables per person and day or a range of 200–600 g (The Eat-Lancet Commission, 2019). Vegetable production is too low to provide sufficient quantities and the average amount of vegetables and fruits combined being available in Sub-Sahara Africa was only 206 g per person and day in 2015 [3]. With this, only half of the WHO recommendation is achieved, provided that these vegetables and fruits were accessible, affordable, and acceptable for each individual of the population.

In rural Ethiopia, people consume a very monotonous diet which consists mainly of two food groups, namely (i) cereals, and (ii) pulses, legumes, and nuts [4]. Micronutrient deficiency is widespread such as iron deficiency with anemia rates among women of 27.3% and among children being as high as 65.5% in the Oromia region [5]. Although malnutrition in children under 5 years of age decreased in Oromia, the rates still remain high: 46.7%, 5.1%, and 21.0% of children were (severely) stunted, (severely) wasted, and (severely) underweight in 2016, respectively [6].

In the Yayu Coffee Forest Biosphere Reserve in Oromia region, southwest Ethiopia, people eat mainly starch based diets with little fruits and vegetables, e.g., in the form of a typical dish of "injera" (prepared from fermented teff (*Eragrostis tef*) flour) with "shiro" (prepared from dried flour of different pulses) [7]). The main income source from agriculture is coffee (*Coffea arabica* L.), which is cultivated in a multi-storey cropping system using shade trees [8,9]. Outside the biosphere reserve and in its transition zone where people reside, it is allowed to prune and cut trees and to cultivate the land. In this area, integrated vegetable production underneath the coffee and shade trees could help add another economically valuable layer to the system and improve the availability of leafy vegetables for better nutrition. However, crop production and in particular the growing area of chat (*Catha eludis* Forsk) is threatening the existence of the remaining coffee forest patches [10,11]. Thus, major challenges to increase vegetable production include the scarcity of land and low acceptance of especially leafy vegetables to be cultivated as they are considered "poor man's food" [12].

Nevertheless, traditional African leafy vegetables are well known to be a good source of different nutrients, especially micronutrients that are in short supply such as iron, calcium, and beta carotene, the pre-cursor of vitamin A, and contribute significantly to food and nutrition security in Africa [13]. Therefore, the NutriHAF—Africa (Improved Nutrition through Horticulture in Agro-Forestry) research and capacity building project implemented between 2015 and 2018, explored and integrated appropriate vegetable crops into multi-storey cropping systems to increase nutrition security, diversify and intensify agriculture and thus to reduce pressure on natural habitats in biodiversity hotspots. The three areas of action were (i) production of vegetables under shade; (ii) recipe development, cooking demonstrations and food preference testing; and (iii) nutritional trainings.

A participatory evaluation of crops locally available and possibly suitable for cultivation under coffee was undertaken. Initially, farmers were reluctant to the idea of growing vegetables under the coffee shrubs. During focus group discussions conducted in 2015, they worried about heavy drops of rainfall damaging the young vegetable germs and about wild animals foraging on the crops. In addition, they stated that they did not know the suggested vegetables and hence would face problems preparing food from them and selling them. Finally, no harm should be caused to coffee shrubs (upper ground) and coffee roots and the area under coffee should be clear during the months of November and December, when coffee is harvested because fallen berries are collected from the ground. Taking these concerns into account, several mostly short duration, leafy vegetables were identified and suggested to farmers [12] and their cultivation demonstrated on farmers' fields and farmer training centers (FTCs) in 2016 and 2017. In a last participatory assessment step, farmer groups chose those crops they were interested to test on their own sites, namely cowpea (*Vigna unguiculata* (L.) Walp.), pumpkin (*Cucurbita* ssp.), and Ethiopian kale (*Brassica carinata*) [12]. Cowpea was known to communities in Yayu as a fodder crop that was previously introduced to the area by the livestock extension agents of the agricultural department but not for human consumption. However, cowpea is traditionally known in many areas of Ethiopia where a diversity of local landraces exist that are used for their leaf yield but also for grains, fodder and as medicine [14]. Crop demonstrations during the first year of this project had indicated that cowpea grew more vigorously than other tested vegetable species in shaded conditions.

The objective of this study was to intensify the existing cropping system and to provide highly nutritious leafy vegetables to the people living close by or in the biosphere reserve including appropriate recipes and trainings on how to prepare the newly introduced vegetables. More specifically, its aim was to assess the performance of cowpea under shaded conditions for leaf production and their acceptance as vegetables by local people. The main research questions were:

1. How does cowpea (*V. unguiculata*) perform under two harvesting regimes in shaded conditions, namely continuous plucking of leaves as compared to complete harvest (uprooting) at the end of the trial?
2. How do local communities accept dishes prepared from the new leafy vegetable cowpea as compared to dishes prepared from the commonly known Ethiopian kale (*B. carinata*)?
3. Based on the production results, to what extent can the selected leafy vegetable contribute to close the gap in vegetable consumption and fulfil recommended dietary allowances for critical nutrients?

An additional aim was to gain practical experience on when production of cowpea can start earliest and until when seeds can be sown latest under rainfed conditions in the project area in order to prolong the cropping season for a maximum spread of the harvest period.

1.1. Agronomic and Nutritional Characteristics of Cowpea

The production of dual-purpose cowpea is common in subsistence farming systems throughout Africa. Its shade tolerance makes cowpea suitable for intercropping, e.g., with maize, sorghum, or millet which is a widespread practice in the semi-arid tropics, particularly in areas where landholdings are small [15]. Agronomic cropping recommendations for cowpea regarding time of sowing, plant spacing, and leaf harvesting period and method exist only for crops grown in sunny conditions, either for mono-crops or for intercropping [15–18].

In open field conditions, if cultivated as monocrop, it is commonly recommended to sow cowpea at a spacing of a minimum of 50 cm × 20 cm [19]. Polreich et al. [20] evaluated the leaf yield of cowpea sown at 75 cm distance between rows and 15 cm distance between plants within a row. Singh et al. [21] studied the effect of spacing on grain and fodder (leaf) yield comparing inter-row distances of 75 cm and 150 cm with hill to hill distances within the rows of 20 cm and two plants per hill. They concluded that it is possible to manipulate the yield (grain vs. fodder) by adjusting the spacing, i.p. to increase the leaf yield with higher crop density. This is in line with Ohler et al. [22] who found the most productive vegetative harvest at high plant densities of 84 to 99 plants m^{-2} in a potted greenhouse trial. Dube and Fanadzo [23] report that both grain and leaf yield of leaf harvested cowpea can be increased by increasing plant density from 15 to 45 plants m^{-2}.

When vegetable cowpea is produced as mono-crop, the harvest is usually done by uprooting the whole plant at the stage when three to five true leaves have developed and before the leaves become too mature and fibrous. In an intercropping system with maize, Saidi et al. [15] showed that harvesting leaves every week produces a higher leaf yield than harvesting leaves only every two weeks and that starting the leaf harvest about three weeks after emergence of the crop has yield advantages compared to earlier and later harvesting initiation times. However, higher harvesting intensity comes at the expense of lower grain yields, but both leaf and grain yields are subject to seasonal variations.

Gonçalves et al. [24] reviewed the literature on the nutritional composition of cowpea. The multipurpose crop that is used for its leaves, green pods, green beans, and mature beans is known to be high in protein and low in fat and to be an interesting source of micronutrients (notably Vitamins of the B complex, Vitamin C, A, and E). However, most research has focused on the nutritional content of cowpea grains and relatively little is known on the nutritional value of leaves. In addition, the phytochemical content of leaves varies depending on the cultivar used and the environmental conditions in which the crop is cultivated. The authors conclude that cowpea leaves could still offer a sustainable and equivalent source of protein and vitamins compared with cowpea seeds, hence fulfilling the basic nutritional requirements of humans [24].

1.2. Study Area

The NutriHAF-Africa project area covered four villages (kebeles) of Yayu and Hurumu districts (woredas), located in the southwestern part of Ethiopian highlands in the Illubabor zone of Oromia State, southwest Ethiopia. These districts are part of the Yayu Coffee Forest Biosphere Reserve which is a biodiversity hotspot and home to a wild gene pool of *C. arabica*. In contrast to most other Ethiopian regions, the study region is highly forested. The altitudes of the hilly landscape vary from around 1100 m up to 2000 masl. The climate is hot and humid, with a mean temperature of 20 °C, and annual rainfalls of 2100 mm. Rainfall follows a clear pattern: low precipitation in January and February, increasing rainfall with a peak between May and October, diminishing again in November and December [25]. This means that, without irrigation, most crops including vegetables can only be grown in the wet, rainy season between May and October.

The biosphere reserve consists of a core area (inner, most protected area), a buffer zone (narrow area around core area) and a transition zone (outermost part of the reserve that is still protected but settlement and farming is allowed). The project activities took place only in the transition zone, which is characterized by smallholder land-use systems that include coffee forests, annual crops on farm land, and horticultural crops, generally cultivated in home gardens. More than 90% of the population works in agriculture, mainly as smallholder subsistence farmers [25]. The major cash crop is coffee that is planted in natural forest areas in the transition zone. Such plantations are maintained by regular weeding of herbaceous plants from the ground and clearing the tree canopy to provide the optimal amount of shade for coffee. Farmers may also harvest coffee from wild coffee shrubs growing in the buffer zone, but no management of these shrubs is allowed.

Another important cash crop grown in the fields is chat (*Catha eludis* Forsk), whereas the most important food crops are maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), and teff (*Eragrostis tef* (Zucc.) Trotter) [9]. Cereals, which are sometimes intercropped with legume crops, have to be guarded during the growing season to protect them from wild animal damage, which is a common problem. The home gardens, predominantly the domain of female farmers, comprise small but diversified plots, where fruits and vegetables, but also coffee are cultivated [7,26]. Fruit and vegetables are seasonally available in the area. The most popular vegetables are Ethiopian kale (*Brassica carinata*), green pepper (*Capsicum annuum*), tomato (*Lycopersicon esculentum*), beet root (*Beta vulgaris* subsp. *vulgaris*), onion (*Allium cepa*), and pumpkin (*Cucurbita* spp.). The most popular fruits are avocado (*Persea americana*), mango (*Mangifera indica*), banana (*Musa acuminata*), papaya (*Carica papaya*), custard apple (*Annona* spp.), guava (*Psidium guajava*) and a variety of citrus fruits (*Citrus* spp.). Cattle production also plays a role with cattle roaming around shortly after cereal harvest and being herded during the cultivation period.

2. Materials and Methods

2.1. Field Trials for Production of Vegetables under Shade

Field trials were established on farmers' fields within the transition zone of the Yayu Coffee Forest Biosphere Reserve, namely in Bondo Megela kebele and Wabo kebele, both situated in Yayu woreda. Cowpea was cultivated during a short duration and exclusively for leaf production. Commonly, it is stated that leafy African Indigenous Vegetables (AIV) have a short cropping cycle and can be harvested after a few weeks of cultivation [16,22,27–30]. However, specific recommendations of the optimal harvesting time are based on cultivation under optimal light conditions. It was expected that the growth of cowpea under shaded conditions would be affected, in particular, they would be slower, smaller (or elongated), and/or lighter [31]. Therefore, initially, it was not known after how many days of growth the optimal harvesting point would be reached.

The trials were set up in a randomized complete block design between April and December 2017 with three replications for the first and second round of trials and four replications for the third and fourth round. Individual plots sizes were 2 m × 3.8 m. Shade was caused by a mix of different trees like mango (*Mangifera indica*), large-podded albizia

(*Albizia schimperiana*), banana (*Musa* sp.), hummingbird tree (*Sesbania grandiflora*), acacia (*Acacia* sp.), and several coffee shrubs (*Coffea arabica*). Seeds for the trials were obtained from the local bureau of agriculture (variety unknown) and the Melkassa research station (variety "Assebot").

Farmers and local technicians cooperated closely for trial implementation and management: both prepared the soil and seedbed; farmers weeded the trial, whereas technicians sowed and monitored the trials on a weekly basis. They counted the survived plants and number of leaves per plant, measured the shoot length as well as the leaf length and width. On each plot, three areas of one square meter were monitored and harvested separately. Bordering plants were not monitored nor harvested.

Treatment one was "continuous plucking", which started two weeks before the final harvest, see Table 1. On each plant, a single full leaf was plucked two weeks and one week before the whole trial was harvested completely. The harvested leaves were weighed. On the final harvesting date, all plants were cut approximately 5 cm above the ground and the weight was taken. After this, the leaves—as edible vegetable—were stripped of the plant and the weight was taken. For treatment two, "harvested at the end", the total above ground biomass and leaf biomass were taken as described above for treatment one at the end of the trial. The planned density for cowpea was 44 plants m^{-2} (interplant distance of 15 cm). Consecutive trials were sown on 26 April 2017, 29 June 2017, 17 September 2017 and 15 November 2017 and were harvested after 83 days, 78 days, and 62 days, respectively. The cowpea trial sown in November 2017 was not harvested because of very poor germination due to dry soil conditions.

Table 1. Cowpea trials in 2017.

	Cowpea Leaves—Harvesting Trial			
Treatment 1	"Continuous plucking" Single full leaf plucked and weighed two weeks and one week before final harvest. Final harvest: all plants cut three fingers above the ground and weighed (total above ground biomass). Leaves (edible part) were stripped off and weighed (leaf biomass)			
Treatment 2	"Harvested at the end" Total above ground biomass taken (as in treatment 1). Leaf biomass taken (as in treatment 1)			
Sowing dates (2017)	26 April	29 June	17 September	15 November
Harvest—days after sowing	83	78	62	-

The leaf count growth rate was calculated by dividing the difference in number of leaves (Δ number of leaves) by the difference in number of days (Δ number of days) from one monitoring date to the next monitoring date: (number of leaves at date b − number of leaves at date a)/(date b − date a). For continuously harvested cowpea plots (treatment one), a new variable adding the leaf weight of the two partial harvesting dates and the leaf weight of the final harvesting date was created.

Data were analyzed with a robust linear two factorial model including interactions using Stata Version 16.

2.2. *Recipe Development, Cooking Demonstrations, and Food Preference Testing*

Recipes for leafy vegetables were adapted to local conditions including locally available and accepted food ingredients. During the cooking demonstrations, the leafy vegetables were shown on demonstration fields and general information about nutritional values was provided. Each step of the cooking process was explained and shown in detail, and participants were also involved in the practical food preparation. Next to dishes with the new vegetable cowpea leaves, also a common dish with the traditional Ethiopian kale as well as with pumpkin leaves were prepared.

Food preference testing was carried out during two extra meetings. The first was conducted in 2016 with pumpkin leaves and Ethiopian kale as a reference for comparison, all vegetables cooked in the same three different ways: with butter, with beans, or with potato. Panelists were randomly selected and totaled 102 people, both women (47) and men (55). Enumerators recorded the results on a five-point Likert scale. The second demonstration and testing in 2017 focused on cowpea leaves only, which were not available in sufficient quantities in 2016. Three different recipes were tested by randomly selected panelists, namely 39 female and 35 male, 74 in total. Cowpea leaves were either cooked alone, with Ethiopian kale and fish, or with amaranth leaves and fish. Again, a five-point Likert scale was applied for recording the liking of the dishes.

2.3. Baseline Survey

A baseline survey was conducted in 2016 in the four project villages. Adopting Yamane's [32] formula for minimum sample size determination, 334 smallholder farmers were selected using stratified sampling techniques. Sample size was proportionate to population size for each study woreda and kebele. Out of the 334 households, 263 were male-headed and 71 female-headed. Through the guidance of development workers at the local level, the villages were stratified in zones and typical cases were selected taking into consideration the representation of each zone at each research kebele. As the four villages were chosen purposely by the project, the results cannot be considered as statistically representative for the biosphere reserve. The survey contained demographic, agronomic, and socio-economic data as well as special questions on vegetable production and consumption for one entire year. The questions on vegetable production and consumption were always directed to women, be it the female household head, or the spouse of a male-headed household. This procedure was justified by the fact that women are the main responsible persons for home gardens, where most vegetables are planted, and for food preparation. This fact was discovered in qualitative interviews with focus groups and key informants carried out by the project before the survey. All nutrition related data, be it obtained from household head or from spouse, relate to entire households (not to individuals).

3. Results

3.1. Production of Cowpea under Shade

When cultivated in plantations, coffee shrubs can be spaced at less than one meter to up to three meters distance from each other. It was assumed that 1.5 m is the minimum distance between coffee shrubs allowing the cultivation of vegetables in between the bushes. The baseline survey revealed that 56 out of 334 respondents reported a distance between the coffee shrubs equal to or larger than 1.5 m. Under-storey cropping of vegetables in coffee plantations would hence be potentially adoptable for about 17% of farmers in the project area.

Germinated plantlets survived and developed into plants as shown below. Cowpea developed similarly during the first six to seven weeks after sowing comparing the three sowing dates (Figure 1). In week seven, shoots were between 17 cm (sown in September) and 26 cm (sown in April) long and grew until 92 cm long in week nine in the case of cowpea sown in April.

The long shoot length resulted from the development of very long vines with relatively small leaves, which started growing once the cowpea canopy was closed. Such vines, however, are not desired when aiming at a high leaf harvest. In addition, the long vines climbed onto the coffee shrubs which was not desired by farmers who worried about a possible damage to their shrubs and about a coffee bean yield reduction.

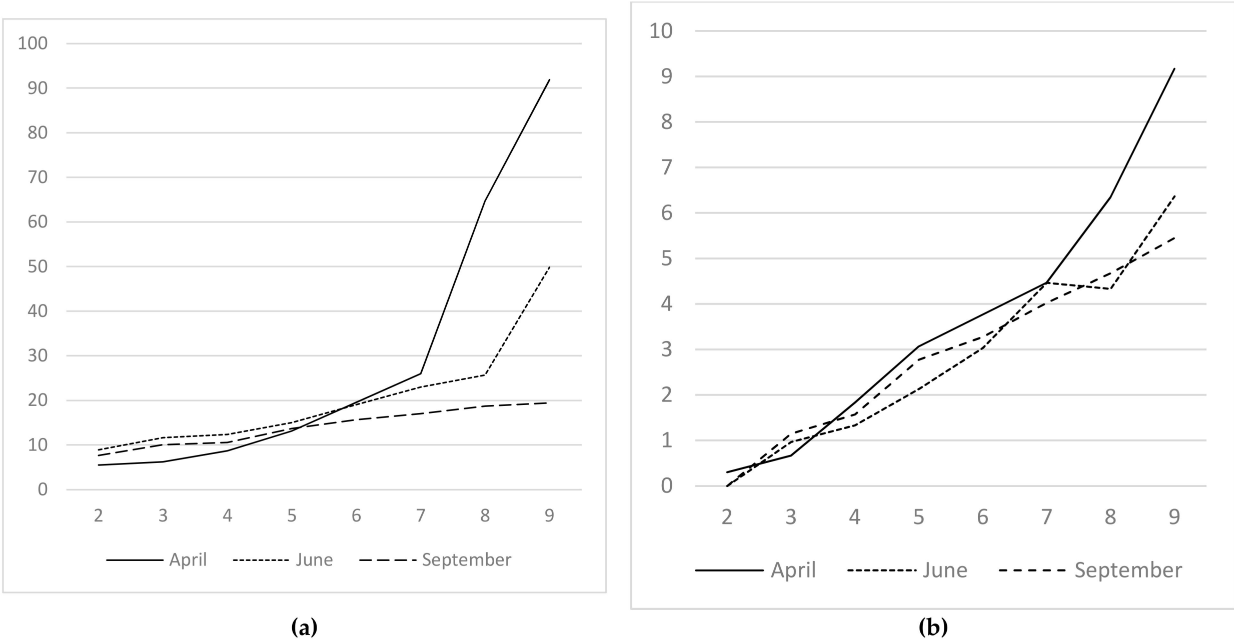

Figure 1. (**a**) shoot growth height (in cm) and (**b**) number of leaves of cowpea grown in shaded locations in 2017 in Yayu, Ethiopia.

Four weeks after sowing, all cowpea had at least one fully developed leaf comparing all sowing dates, reaching the three leaf stage between week five and six and the four leaf stage in week seven. The growth rate of the number of leaves per plant per day (leaf count growth rate) started at a similar level of about 0.15 leaves per day for the trials sown in April and September which were sown in the same trial plot (Figure 2). While the wetter period starting in April resulted in a steady growth rate of 0.175 leaves per day between week 5 and 7, plants sown in September developed new leaves at a slower pace (growth rate of about 0.1 leaves per day), due to the dryer soil condition at the end of the rainy season. The trial sown in June was set up at a different location and had a different pattern of leaf development: it started at a slower pace in week four, increased to about 0.2 in week seven, followed by a slightly negative development of new leaves. This might be due to several cases of leaf senescence which were, however, recovered in week nine.

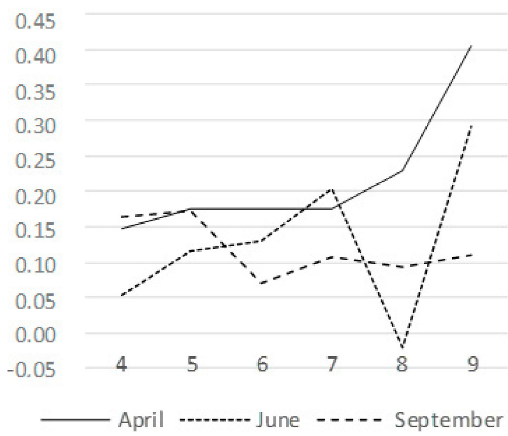

Figure 2. Leaf count growth rate of cowpea grown in shaded locations in 2017 in Yayu, Ethiopia.

Cowpea yielded between 1.2 kg m^{-2} (12 t ha^{-1}) leaves when sown in June and 2.6 kg m^{-2} (26 t ha^{-1}) leaves when sown in April using the continuous plucking method (Table 2). In all trial rounds, the cumulatively harvested leaf yield was significantly higher than the leaf yield of the whole plant harvested once over at the end of the trial. The mean leaf yield over the three consecutive trials was 1.815 kg m^{-2} (18.15 t ha^{-1}) for continuously plucked cowpea and 0.656 kg m^{-2} (6.56 t ha^{-1}) for cowpea harvested at the end of the trial. Accounting for a slightly uneven plant density, the leaf harvest per plant was calculated and compared (Table 3). Again, the difference in yield between continuously harvested and singly harvested plants was significant (Figure 3).

Table 2. Mean cowpea leaf biomass harvest (kg m^{-2}) by treatment and trial round in 2017.

Trial Round	Continuous Plucking	Harvested at End	*p*-Value (*)
April	2.589 ± 0.554, N = 3	0.957 ± 0.347, N = 9	0.000
June	1.202 ± 0.620, N = 9	0.476 ± 0.039, N = 9	0.004
September	2.081 ± 0.689, N = 12	0.565 ± 0.374, N = 12	0.002

Note: Mean ± standard deviation; * post hoc test after robust linear two factorial model including interactions.

Table 3. Cowpea leaf biomass harvest (kg) per plant (accounting for varying plant density) by treatment and trial round in 2017.

Trial Round	Continuous Plucking	Harvested at End	*p*-Value (*)
April	0.088 ± 0.014, N = 3	0.033 ± 0.012, N = 9	0.000
June	0.042 ± 0.029, N = 9	0.015 ± 0.001, N = 9	0.010
September	0.062 ± 0.020, N = 12	0.017 ± 0.011, N = 12	0.002

Note: Mean ± standard deviation; * post hoc test after robust linear two factorial model including interactions.

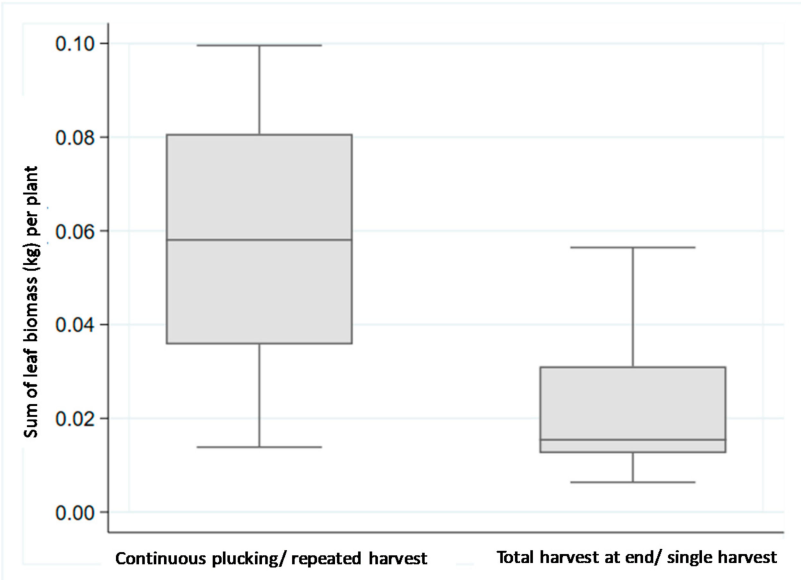

Figure 3. Cowpea leaf biomass harvest (kg) per plant (accounting for varying plant density) in 2017 (post hoc test after robust linear two factorial model including interactions, $p = 0.000$).

3.2. *Recipe Development, Cooking Demonstrations, and Food Preference Testing*

In 2016, from 102 participants in total during the food preference testing, about 47% and 45% liked the dishes with the common Ethiopian kale and the newly introduced pumpkin leaves very much. About 38% and 40% stated to like Ethiopian kale and pumpkin leave dishes, respectively; and only 15% were undecided (both vegetables) while nobody stated to dislike the dishes (Figure 4). Gender disaggregated data analysis (data not shown) revealed that there is no gender difference in vegetable dishes' taste preference among the panelists. Apparently, pumpkin leaf dishes were liked in the same way as Ethiopian kale dishes, which served as a reference.

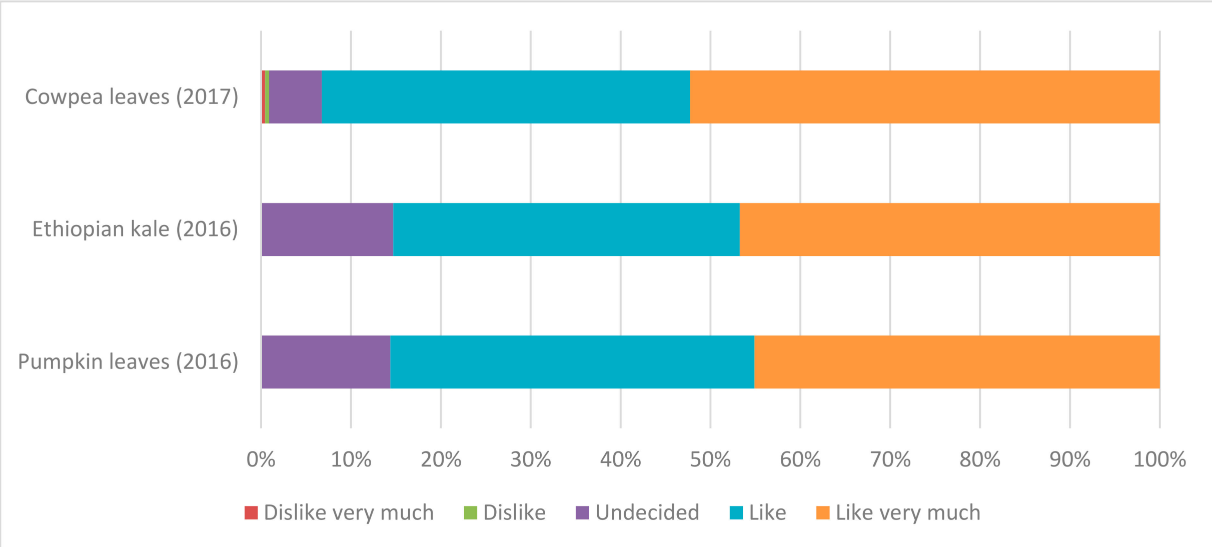

Figure 4. Taste rating of dishes with different leafy vegetables by panelists (average of three dishes with various ingredients); N = 102 for pumpkin leaves and Ethiopian kale; N = 74 for cowpea leaves.

In 2017, only cowpea leaves were tasted without the direct comparison to Ethiopian kale and also using different recipes than in 2016. However, the picture for cowpea leaves was similar with 52% of participants liking the dishes very much, 41% liking them, only 6% being undecided and only two people disliking the dishes. Although different recipes were used, cowpea leaves were even more liked than Ethiopian kale which could be due to the different recipes; however, at least they were well accepted by the large majority of participants. There was also no significant difference between the recipe in which cowpea leaves were cooked alone or with amaranth leaves and the recipe in which it was cooked with Ethiopian kale. Consequently, it is important to note that the newly introduced vegetables are liked similarly to the common Ethiopian kale.

3.3. Combining Vegetable Production and Consumption Data: Possible Contribution of Cowpea Leaves to the Local Diet

3.3.1. Low Vegetable Consumption

It is known from previous studies that vegetable consumption is low in Ethiopia and on average only about 1/6 of the vegetable consumption recommended by WHO [33]. This was confirmed in the NutriHAF Project baseline study. For example, around 80% of households do not consume any carrots (as a source of vitamin A) and nearly 40% do not consume any cabbage (as a possible source of vitamin C). In fact, only about half of the households (52%) consumed vegetables on the day prior to the survey and even only 8% of all households consumed dark green leafy vegetables on the previous day. The only leafy vegetable consumed 24 h prior to the interview was Ethiopian kale. Kale is produced by two thirds of farm households, and consumed in general by nearly all (94%) households, on average, 37 kg per year (baseline survey). Nevertheless, because of missing irrigation facilities, it is mainly consumed during the rainy season, between May and October (for six months during the year). Ethiopian kale is a good source of vitamin A (740 µg/100 g raw edible portion) and vitamin C (70 mg/100 g) as well as of iron (1.5 mg/100 g) [34,35]. Besides Ethiopian kale, cowpea leaves could contribute to the provision of vitamin A (about 520 µg/100 g raw edible portion) and vitamin C (33 mg/100 g) as well as iron with on average 3.1 mg/100 g raw edible portion [34]. In addition, cowpea vegetables have antioxidant properties through different carotenoids [36] and add more variety and different tastes to the diet, which can make eating vegetables more attractive.

3.3.2. Increasing Consumption of Vegetables

Based on the above results from growing vegetables under shade, cowpea leaves could yield between 1.2 kg m^{-2} and 2.6 kg m^{-2} so that from an area of 25 m^2 a household could harvest between 60 kg and 130 kg of leaves from their coffee garden per season assuming two harvests during the six-month rainy season (Table 4). This amount would mean that, for half a year (183 days), about 328–710 g of cowpea leaves per day for the household. Following the dietary recommendation of 200 g of vegetables per adult per day, cowpea leaves alone would cover the needs of about 1.6–3.5 adults. As it is rather unrealistic that the total amount of cowpea leaves harvested will also end up on the plate, we assumed post-harvest losses of either 10% or 30% (adapted to local conditions from FAO, estimating fruit and vegetable losses of 10% to more than 50% for sub-Saharan Africa, depending on how many value chain stages are included) [37] and also calculated the amount available per week because daily harvesting is rather unlikely. Reversely, the area needed to provide enough cowpea leaves so that one adult is provided with 200 g per day ranges between 7.6 and 21.8 m^2 while, for a typical family, an area between 34.4 and 98 m^2 would be needed (Table 4).

Table 4. Contribution of cowpea leaves to the individual and household vegetable consumption *.

	No Post-Harvest Losses	10% Post-Harvest Losses	30% Post-Harvest Losses
Leaf yield (kg) from 25 m^2 (under shade) during 6 months (183 days)	60–130	54–117	42–91
Available amount of leaves (g) per day during 6 months (183 days)	328–710	295–639	230–497
No. of adults who could consume 200 g per day (1.4 kg per week) **	1.6–3.6	1.5–3.2	1.2–2.5
Area (m^2) needed to provide 200 g per day for 1 adult (36.6 kg for 183 days)	7–15	8–17	9–20
Area (m^2) needed to provide sufficient leaves for a typical family of 5 people ***	32–69	35–76	41–89

* Assuming the cropping under shade with a total yield of 2.4 kg to 5.2 kg per m^2 during the rainy season of 6 months; ** According to the WHO recommendation of consuming 400 g fruits and vegetable per day [2]; *** According to the baseline survey a typical household consisted of three adults, one child and one infant; vegetable amounts per day are 200 g for adults and children and 100 g for infants.

3.3.3. Increasing Nutritional Yield

To calculate the nutritional yield means to calculate the number of adults who can obtain 100% of annual recommended dietary allowance (RDA) of certain nutrients provided by a specific crop from 1 ha per year [38]. As the vegetables are not available for the whole year but only seasonally, we calculated the nutritional yield from 25 m^2 per six months. This calculation for cowpea leaves needs to be done with caution as nutritional values can differ substantially between varieties and cropping conditions such as insolation, soil type and water availability. Nevertheless, a range of values should be given here for vitamin A, iron and vitamin C based on the above-mentioned nutrient contents of the vegetables. About 154 g edible portion of cowpea leaves per day or 28.2 kg per six months would be needed to fulfil the RDA for vitamin A for an adult (average of male and female 19–50 years). Consequently, with the proposed amount of cowpea leaves harvested, this would be sufficient for 2.1–4.6 adults for six months. To fulfil the RDA for iron, a larger amount is needed, namely about 433 g edible portion of cowpea leaves per adult per day or 79.3 kg in six months. The harvested amount from 25 m^2 would be sufficient to fulfil the RDA for iron for 0.8–1.7 adults for six months. In order to fulfil the RDA for vitamin C about 250 g, the edible portion of cowpea leaves needs to be consumed by an adult per day or 45.8 kg in six months. The possible harvest could provide sufficient vitamin C for 1.3–2.9 adults. Reversely, the area needed to be cultivated with cowpea leaves in the coffee forest in order to fulfil the RDA for one adult would be 5–12 m^2 for vitamin A, 15–33 m^2 for iron and 9–19 m^2 for vitamin C. When looking again at a typical family with about five (4.7) household members (baseline survey), the area needed would be between 22 and 125 m^2 assuming no post-harvest losses (Table 5).

Table 5. Contribution of cowpea leaves to the recommended daily allowance (RDA) of iron, vitamin A, and vitamin C compared to Ethiopian kale *.

		Iron	Vitamin A	Vitamin C
For 1 adult (average for male and female 19–50 years)	Average RDA (mg/day)	13	0.8	82.5
	Cowpea leaves needed for 6 months (kg)	79.3	28.2	45.8
	Cowpea area needed for 6 months (m^2)	15–33	5–12	9–19
	Ethiopian kale area needed for 6 months (m^2) ***	16–79	2–10	2–11
For a typical family of 4.7 members **	Average RDA (mg/day)	49.1	3.3	315.1
	Cowpea leaves needed for 6 months (kg)	299.6	116.9	174.7
	Cowpea area needed for 6 months (m^2)	58–125	22–49	34–73
	Ethiopian kale area needed for 6 months (m^2) ***	60–300	8–41	8–41

* Assuming the cropping under shade with a total yield of 2.4 kg to 5.2 kg per m^2 during the rainy season of 6 months/183 days (assuming no post-harvest losses)—as compared to Ethiopian kale grown in the home garden during the rainy season (two harvests, no losses); ** Consisting of 0.5 infants (0–5 years), 0.5 children (6–10 years), 0.8 children (11–15 years), 2.6 adults (16–64 years) and 0.3 adults (>64 years); *** Minimum yield: 1 kg/m^2, maximum yield: 5 kg/m^2 [16].

4. Discussion and Conclusions

Cowpea was successfully cultivated below coffee in shaded growing conditions in the Yayu Coffee Forest Biosphere reserve in 2017. The worry of farmers and local experts that vegetable plants would not survive in the darker conditions with heavy rain drops falling constantly from the tree canopy during the rainy season was hence unnecessary. Repeatedly harvested cowpea under shade produced significantly more leaves than cowpea that was harvested once-over.

Dube and Fanadzo [23] reported that cowpea reached the three leaf stage two weeks after crop emergence. Hence, the shaded growing conditions in this study have retarded crop growth since plants reached the three-leaf stage only five to six weeks after sowing. From these results, it can be concluded that leaf harvesting can start after approximately seven weeks, when the plants developed at least four leaves. The calculated leaf count growth rate confirms the conclusion drawn above that a good start of leaf harvesting is about seven weeks after sowing. This is similar to the results of AVRDC-RCA Tanzania, presented in Oluoch et al. [29]. A trial conducted in 2005 showed that starting the leaf harvest eight weeks after sowing gave the optimum total leaf yield. The authors report total leaf yields of 85.1 g/plant and 28.4 t/ha when the harvest started in week seven and 100.9 g/plant and 33.6 t/ha total leaf yield when the harvest started in week eight. Irrespective of the harvest timing, the three cultivars included in the trial, Tumaini, Dakawa, and Fahari, yielded 86.5, 52.4, and 82.1 g/plant (28.8, 17.5, and 27.4 t/ha), respectively, in 2005. In a trial in 2006, the same varieties yielded 92.3, 85.3 and 105.0 g/plant (19.1, 17.3 and 21.2 t/ha), revealing considerable seasonal differences. However, it is not reported how intensely leaves were harvested in Tanzania [29]. The leaf yields measured in the present study were 18.15 t/ha (mean over the tree consecutive trials) for continuously plucked cowpea which is within the range of Tanzanian yields from the year 2006. This is striking because it means that the yields produced under shade are comparable to yields produced in Tanzania in a less than optimal year. In other words, the yields under shade do not seem to be different from a yield produced in open experimental field conditions in a bad year. Although this is encouraging, the cultivation of vegetables under shade would need further research.

Leaves should be harvested at such an intensity that it helps to avoid full canopy closure, hence preventing the development of elongated shoots with small leaves. These shoots climb on the coffee shrubs and could cause damage to the important cash crop.

Although cowpea under shade developed slower than cowpea in open field conditions, farmers in Yayu would be able to continuously harvest leafy vegetable cowpea during the majority of the rainy season, from mid-May to September/October, depending on the rainfall. Experience gained from the field trials points to an end of the rainfed vegetable cropping season in December since cowpea seed sown in December 2017 did not germinate. It also showed that sowing could start earlier than initially thought by local experts, namely with the onset of the rainfall which can be as early as the beginning of April.

The presented trials give the first important answers on the possibility of intensifying the local cropping system. However, many questions remain open or newly emerge from these results that could not be answered in the present study. Although the trials showed the superiority of continuous plucking over a harvest of the full crop at the end of the trial, it could still be advantageous for farmers to practice the uprooting of cowpea at the three to five leaf stage as commonly practiced by many African farmers [15]. Staggering the sowing dates of small areas of cowpea and continuously harvesting and re-sowing the crop (e.g., every week) could optimize the leaf yield of the entire cropping season compared to the setup of the present trials. Future research should also precisely assess and account for the time requirement of different harvesting methods which was only done in a too rough manner in this set of trials. Women who harvest the leaves might well prefer a less time-consuming procedure over a higher overall leaf yield if the latter can only be achieved with higher work input.

In each trial, only one cowpea variety originally distributed as animal fodder crop was tested while a wide range of cowpea landraces exist in Ethiopia [14]. These might not differ much in terms of leaf taste but in terms of leaf size and overall consumer acceptability [39]. In addition, the landraces selected for human consumption by farmers might be superior to the variety we have tested in this study in terms of their leaf yield, suitability to thrive under shade or other criteria relevant to farmers. Therefore, it would be of interest to conduct varietal trails in the given settings of the Yayu Coffee Forest Biosphere Reserve.

The intercropping of cowpea and coffee might have other positive or negative effects that could not be studied in this set of trials, e.g., nitrogen fixation and weed suppression. Matikiti et al. [40] assessed the effects of leaf harvesting frequency and intensity on nodulation of cowpea and found that an increased harvesting intensity and frequency decreased nodule dry weight significantly.

A limiting factor for early vegetable production could be the availability of land that is protected against free roaming cattle. During the time of the year when no major crops are on farmers' fields, the livestock is not guarded and searches for feed on their own. As soon as crops like maize and teff are sown, children or elderly people take over the role of herders to protect the crops. This job would have to start earlier if early vegetables were cultivated.

Another worry of farmers was related to the problem of crop raiding by wild forest animals like olive baboons (*Papio anubis*) and bush pigs (*Potamochoerus larvatus*). Similar to the situation in Yayu, Ango et al. [41] reported that crop raiding undermined the willingness of farmers to adopt new technologies. In their study, farmers located near forests reported that 85% of their fields were visited by at least one type of wild animal pest. The above reported figure of 17% of coffee plantation area that is potentially suitable for shaded vegetable production would have to be modified taking into account the coffee plantation's location relative to large forest areas. It is speculated that coffee forest patches that are isolated from larger forest areas are possibly more suitable than coffee plantations integrated into larger forest areas where wild animal pests are likely to be more prominent and that farmers are hence more willing to adopt shaded vegetable production in isolated coffee forest patches.

The double to triple higher yields of continuous plucking vs. single harvesting seems to make this method clearly preferable for farmers. Besides higher yields, it also provides leaves for a more continuous consumption. Nevertheless, the continuous plucking method is also more time-consuming, not only because of a more frequent harvesting, but also because of the time spent for going to the shaded areas. Coffee forests are often far away from homesteads. In these cases, harvesting time would probably cause high opportunity costs for farmers. Moreover, it is mostly women who are responsible for vegetable production and harvesting [42]. Women prefer a location close to their home, which makes the home garden a specially suited place for cowpea production, also under (half or full) shade.

The consumption of cowpea leaves could improve nutritional health and be a complement to Ethiopian kale as the leaves contain about twice as much iron as Ethiopian kale, the single most popular leafy vegetable in Yayu (baseline survey). At the moment, the actual average amount harvested of Ethiopian kale (37 kg/household per year) allows fulfilling the RDA of iron only for 11 days. The yield of cowpea leaves from 25 m^2 in the coffee forest could cover in addition the need of iron for a family for 18–40 days, and thus could make a substantial contribution to household diets. To cover the RDA of iron with Ethiopian kale, in the home garden and in full sun, a larger area is needed compared to cowpeas in shaded areas. In any case, cowpea leaves could be an addition to diversify both the cropping system as well as the diet.

The challenge of the nutrient calculations is that these values refer to the raw edible portion and the concentration of nutrients; in particular, vitamins might be reduced through certain preparation methods, such as boiling and frying and through low bioavailability of iron at the time of vegetable consumption. Moreover, the nutrient contents in cowpea leaves differ by variety cultivated and are influenced by the interaction with the environment in which cowpea is cultivated [24]. Therefore, the phytochemical content of cowpea would need to be reassessed for crops grown in low light intensities. Assuming that more different vegetables such as Ethiopian kale, tomatoes, onions and others are consumed; in addition, the growing of cowpea in the coffee forest could contribute to a more balanced diet and would largely contribute to closing the dietary gap between current dietary patterns and recommended food intake in Ethiopia.

Although the average coffee forest area of around 0.8 ha per coffee grower is relatively large, only 17% of farmers have large enough planting distance (of 1.5 m or more) between coffee plants to cultivate vegetables between coffee rows. However, assuming that only 10% of the interviewed farmers (n = 334) grow cowpea in the shade on 25 m^2, each farmer could harvest up to 130 kg, together max. 4420 kg. This would be more than one third (36%) compared to the current production of Ethiopian kale (12,380 kg). However, this calculation is only hypothetic because many factors influence farmers' adoption decision besides the availability of space between coffee rows.

The development of recipes incorporating vegetables in tasty and attractive meals is extremely important to increase consumption. Appropriate combinations of different ingredients can make the consumption of vegetables a pleasant experience and also optimize the supply of essential nutrients [43]. The participatory cooking demonstration and food testing has positively changed the attitude of participants towards the newly introduced leafy vegetables. Right after the training on the micronutrient contents of these vegetables followed by the participatory cooking demonstration, participants requested seeds of these crops for cultivation on their land.

While the food testing showed that the acceptance of the newly introduced vegetables was high, it was not surveyed by the project whether this also translated into continuous consumption at home. Long-term effects of nutrition education and implementation of newly acquired techniques or recipes were demonstrated in previous projects such as in Malawi [44] or in South Africa where nutrition education improved specific dietary behavior as tested 12 months after intervention [45]. Even without being able to give final, conclusive results, it seems that the holistic approach taken by the NutriHAF project of introducing innovative vegetable production systems, combined with testing of new recipes and nutrition education, is a promising one for achieving better food and nutrition security.

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