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Production of Fruits and Leafy Vegetables *Solanum nigrum* Linn under Different Shade Levels

Nani Yulianti[A,B], Edi Santosa[C,*] and Anas Dinurrohman Susila[C,D]

[A] Department of Agrotechnology, Faculty of Agriculture, Universitas Djuanda Bogor, Jl. Tol Ciawi No 1, Bogor 16720, Indonesia
[B] Graduate School of Agronomy, Faculty of Agriculture, Bogor Agricultural University, Jl. Meranti Kampus IPB Darmaga, Bogor 16680, Indonesia
[C] Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Jl. Meranti Kampus IPB Darmaga, Bogor 16680, Indonesia
[D] Center for Tropical Horticulture Studies, Bogor Agricultural University, Jl. Raya Pajajaran Kampus IPB Baranangsiang, Bogor 16154, Indonesia

*Corresponding authors; email: edisang@gmail.com

Abstract

Fruits and young shoot of *Solanum nigrum* Linn are harvested and consumed as indigenous vegetables by different Indonesian ethnics. Preharvest factors and harvesting methods to maximize the quality of *S. nigrum* produce is still unknown. In this study *S. nigrum* was grown in full irradiance and under shading and assessed for their growth, and fruit and shoot yields. The experiment was conducted at the Leuwikopo Experimental Farm in Bogor Agricultural University, Indonesia from April−July 2017. The results demonstrated that plants produced more fruits and shoots in full irradiance, i.e. 687.9 g and 211.1 g per plant, whereas only 331.1 g and 116.9 g per plant were produced in 50% shading. Although fruit and shoot production were superior under full irradiance, shoot-harvested plants had healthier leaves and life span of about 2 months longer thus facilitating longer availability. Canopy of shoot-harvested plants formed a columnar shape with 23 to 45 cm in height, in contrast to spherical shape with 48 to 203 cm in height of the fruit-harvested plants. It is likely that shading level might contribute to farmers' decision to harvest the shoots or fruits of *S. nigrum*. Further studies are needed to determine the effects of shading levels on nutritional quality of the shoots and fruits of *S. nigrum*.

Keywords: African nightshade, canopy architecture, harvesting method, indigenous vegetable, intercropping

Introduction

African nightshade (*Solanum nigrum* Linn) is widely spread in Asia, Africa and North America (Edmonds and Chweya, 1997; Sarma and Sarma, 2011). *S. nigrum* fruits and young shoots have been traded and consumed locally as an indigenous vegetable in many African and Asian countries (Edmonds and Chweya, 1997; Santosa et al., 2015; Onyango et al., 2016; Iskandar et al., 2018). The *S. nigrum* fruit is a good source of protein, Ca and P, and vitamins such as vitamin A, B1 and C (Soetiarso, 2010). Aqueous extract of fruit contains alkaloids and flavonoids that have the ability to inhibit spermatogenesis, may act as an antioxidant and may relieve diabetic and other pharmacological activities (Edmonds and Chweya, 1997; Rahardianingtyas et al., 2012; Setia, 2012; Iryani, 2017; Umamageswari et al., 2017). The same effect on diabetes is also observed on leaf extracts (Maharana et al., 2011; Nulfitriani et al., 2013; Suhendar, 2014; Dasgupta et al., 2016).

In Indonesia, *S. nigrum* is locally named *leunca* (Sundanese), *ranti* (Javanese) and *bobosa* (Moluccas) (Susila et al., 2012). Sundanese in west Java mostly consumes fruits as pickles, while Javanese in central Java prefer young shoots as vegetables (Santosa et al., 2015; 2017). Nevertheless, the reason why these ethnic groups utilize this vegetable in different ways is still unclear. Presumably different cultivation methods and risk sharing might have affected the preference of parts of the plants harvested for consumption (Ekawati et al., 2010; Permatasari, 2013; Santosa et al., 2017). Our preliminary study shows that farmers in west Java grown *S. nigrum* in monoculture while in central Java *S. nigrum* is mostly intercropped or grown under tree shades.

It is known that continuous utilization of a particular plant by a particular ethnic group is based on its yield and flavor, easiness of cultivation, gender perspective, medicinal, economic and functional value (Casas et al., 1999; Santosa et al., 2003; Ulrich, 2008; Ekué et al., 2010; Vodouhè and Dansi, 2012; Karambiri et al., 2017). In *Vitellaria paradoxa*, Bobo ethnic in Burkina

Faso prefers to variety that is resistant to changes of rainfall, whereas Mosse ethnic prefers variety with early fruit yield (Karambiri et al., 2017). Casas et al. (1999) reported that domestication process of *Stenocereus stellatus* in Mexico mainly to select the variety that suitable for growing under silviculture. According to Santosa et al. (2003) Javanese claim that the young leaves of *Amorphophallus paeoniifolius* from shaded plants have better taste than those from full sun. Ekawati et al. (2010) reported that many indigenous vegetables are suitable for growing under shade, as indicated by its higher biomass production. In tomato, shading treatment avoids the problem of high temperature and high irradiation during growing period leading to the higher fruit quality (Gent, 2007). In our current experiment, growth of *S. nigrum* under shade with different harvesting methods was compared with those grown in full sun. The objective of the study was to evaluate the growth and the yield of *S. nigrum* under full sun and 50% shading on fruits and shoots production.

Materials and Methods

The experiment was conducted at the Leuwikopo Experimental Farm, in Bogor Agricultural University, Bogor, Indonesia, at the end of our rainy season which was from April to July 2017. Plants were maintained in the field at Darmaga; the type of soil is Latosol. Average daily air temperature during the study was 21.3 ºC, air relative humidity was 86.7%, and average monthly rainfall was 52.7 mm (Weather Station of Darmaga, Bogor).

Plant growth and production under 50% shading were tested with no shade as the control. Black net shades with 50% reduction in light intensity were installed at 2 m above the soil surface from planting to harvest. Under each shading treatment the plants were arranged into two groups for harvesting shoots or fruits. Shoot harvesting was started at 4 to 5 weeks after planting (WAP) while fruit harvesting was started at 5 to 6 WAP. Harvesting of fruit and young shoots was carried out once a week. In total, 8 to 9 harvests were conducted during the course of the study. All treatments were conducted with three replications. Five plants from each treatment were scored.

The *S. nigrum* seeds were a local accession from Bogor (Collection of Dr. Edi Santosa). Before planting, the seeds were sown in the seedling tray and maintained for a month prior to transplanting to the field. Seedlings of approximately 13 to 20 cm in height were planted at a distance of 60 cm × 100 cm in raised beds of 2.5 m long x 1.2 m wide with 30 cm between beds. Each bed was considered as a unit of replication.

The cultivation method employed was from Putriantari and Santosa (2014), including the rates of NPK fertilizers applied. Cow manure at 5 $t.ha^{-1}$ was incorporated into the soil a week before planting. Urea (46% N), KCl (60% K_2O) and SP-36 (36% P_2O_5) fertilizers were applied at rate 120 $kg.ha^{-1}$. N fertilizer was applied three times, i.e., at 1, 6 and 11 WAP, whereas all P and K fertilizers were applied at planting. Plants were watered every two days, except on rainy days.

The parameters measured were plant height, canopy width, number and weight of fruit, shoot weight, number of leaves per plant, root length and root density. These parameters were measured weekly, whereas dry mass and roots were measured at end of the growing season (16 WAP). Plant height was measured from the soil surface to the tip of the growing point, while the canopy width was measured from tip-to-tip of the longest opposite branches. Fruits were harvested according to the marketable standards, i.e., fully matured leaves with dark green color; and fruit weight included the peduncle. Young shoots were cut using disinfected scissors considering 100% edible portion (5 to 15 cm in length). The data was subjected to a *t*-student test (paired test) at 5% level of confidence. All analysis was done using SPSS 16.0 statistical program.

Results and Discussion

Canopy Architecture and Plant Growth

Shoot elongated about 10 to 20 cm per week at full irradiance and 10 to 30 cm under 50% shading. Plants had rapid growth at 2 to 9 WAP and reached a maximum height of the canopy at 12 WAP. The first shoot harvesting was done at 5 WAP when the plant height was about 70 cm; while the first fruit harvesting was done at 6 WAP. After the first shoot harvesting, the rest of the axillary buds elongated to about 20 cm per week in the control and 30 cm under 50% shading. Thus, new shoot growth was more pronounced under 50% shading.

Canopy of shoot-harvested plants (SHP) and fruit-harvested plants (FHP) exhibited differences in height, irrespective of the shading treatments (Table 1). SHP had a constant height after the first harvest at 4 WAP until 16 WAP, i.e. 59 cm in full sun and 62 to 81 cm in 50% shade. SHP plants from both under no shade and 50% shading treatments showed no significant difference in their heights, except at 16 WAP. It is obvious that shoot harvesting inhibited shoot branching. There was a significant difference in the internode length of all the different shade levels with both the SHP and FHP having a slightly longer internode under 50% which is about 30 to 100% longer than that under full irradiance. Similar responses to shade were recorded on the canopy width (Table 1).

On the other hand, FHP canopy increased in height until 12 WAP (Table 1). After 12 WAP the plant height stabilized at about 112 to 124 cm although the side shoots continued to elongate. In this case, plant height was measured from soil surface to the top of the canopy. The stable height was due to the subsequently grown shoots tend to bend down of heavy fruit load, irrespective of shading treatments, leading to shorter plant height at 16 WAP as shown in Table 1.

Intensive shoot harvesting promoted canopy to form columnar shape in SHP, while FHP canopy had a spherical shape irrespective of the shading treatments (Figure 1). Morphologically, the node of *S. nigrum* had many side shoots; and the inflorescences emerged in the middle of the young internode near the growing point. Indeed, there was a tendency that later shoots had a shorter internode resulting in more dense leaves and fruit arrangement at the top of the plant, especially after 12 WAP. On the other hand, fruit harvesting did not cause alteration on shoot growth. Santosa et al. (2017) reported that canopy shape of *S. nigrum* is influenced by nitrogen fertilizer. In this study, the canopy architecture was more determined by the plants parts that were harvested (shoots or fruits).

Table 1. Plant height and canopy width of *S. nigrum* grown in full sun and 50% shade harvested for shoots and fruits at 4 to 16 weeks after planting (WAP)

Parts harvested	Shading (%)	Plant height (cm) at			
		4 WAP	8 WAP	12 WAP	16 WAP[z]
Shoot	0	58.7±2.4	tb	tb	58.8±4.0
	50	62.4±2.2	tb	tb	80.5±11.5
		ns	ns	ns	*
Fruit	0	60.5±7.1	111.1±7.8	123.2±11.1	111.8±6.8
	50	69.9±7.2	123.8±9.5	129.5±11.5	123.8±16.6
		ns	ns	ns	ns
		Canopy width (cm)			
Shoot	0	-[y]	42.2±1.2	30.7±2.1	29.7±3.1
	50	-	29.1±4.4	24.0±3.6	28.7±1.5
		-	*	ns	ns
Fruit	0	-	91.3±12.0	124.2±19.2	203.7±48.8
	50	-	88.4±67.7	121.1±8.6	169.0±7.8
		-	ns	ns	ns

Note: values are mean±S.D; *significantly different at t-test α 5%, **very significantly different at t-test α 1%; ns: not significantly different; WAP: weeks after planting; tb: plant height is similar to 4 WAP; [z]The fruit-harvested plants were shorter at 16 WAP than at 12 WAP due to the canopy had bent down; [y]No observation was conducted.

Figure 1. Canopy architecture of *S. nigrum* at different shading levels and part of plants harvested. A1: shoot-harvested plant (SHP) on full sun; A2: SHP on 50% shading; B1: fruit harvested plant (FHP) on full sun; B2: FHP on 50% shading; C1: harvested shoots; C2: harvested fruits. Otherwise stated bar is 50 mm.

Interestingly, SHP had almost 2 months longer life than those of FHP (data not shown). At the time the study was terminated, the SHP still continued to produce new shoots, especially in the 50% shade condition. Nevertheless, the observation had to be terminated to minimize environmental bias due to drought/lack of rainfall. In July to August 2017, the monthly rainfall was recorded zero. According to information from farmers in Banjarnegara, Central Java, *S. nigrum* plants that grow along the irrigation channel and under shading can live all year round (Dr Edi Santosa, *personal communication*). However, further research is needed, especially to understand the long-term growth behavior of *S. nigrum* under shades in combination with water availability.

Yield

The initial harvesting time for fruits and shoots was slightly different. The first fruit was collected at 6 WAP and 7 WAP from plants grown in full sun and 50% shading, respectively; the shoots were harvested for the first time at 5 WAP from both full sun and 50% shaded plants (Table 2). Flower emergence was delayed about one week under shading, resulting in a later initial fruit harvest. Delaying of flower emergence due to shade treatment has been reported in *S. nigrum* (Ferre et al., 2009; Masabni et al., 2016), as well as in the other Solanaceae species (Kartika et al., 2015). On farmers' field *S. nigrum* shoots were harvested at 3 weeks after sowing (Dr Edi Santosa, unreported research); this means that S. nigrum grown for the shoots can be harvested earlier than hose harvested for the fruits. According to Putriantari and Santosa (2014), fruits harvested every 5 to 6 days have the best quality for consumers.

Table 2 shows that average monthly shoot yield during harvesting time was higher under full sun than that of 50% shading. Monthly fruit yield, on the other hand, was statistically similar in both treatments, i.e., 113.2 and 242.9 g per plant. Thus from economical point of view, fruit production provided more benefit as the income from fruit production was about two times more than shoot production in both sun levels (Table 2).

Weekly fruit yield showed bimodal pattern irrespective of shading levels (Figure 2); and this is in line with findings of Putriantari and Santosa (2014). Peak of fruit yield were at 9 and 15 WAP; and 50% shaded plants had lower fruit yield than under full irradiance (Figure 2A). In general, regardless of shade treatments, there was variation in the number of fruits per cluster, e.g., 1 to 12 fruits (on average 4 to 7). It is important to note that fruit set was nearly 100%, meaning that low number fruit production under 50% shade treatment is due to limited number of inflorescence clusters. On average, individual plant produced about 10 to 40 fruit clusters at any harvesting time, while the number of shoot was 20 to 25. A total fruit harvest of 687.9 g in full irradiance were formed from 191 fruit clusters, whereas under 50% shading of 331.2 g were formed from 98 fruit clusters. This means that average cluster weigh 3.6 g in full irradiance and 3.4 g in 50% shading. Santosa et al. (2017) reported the high correlation between the number of flower cluster and the number of internode. Thus, efforts to stimulate plant to produce more side shoots are important in *S. nigrum*. Unlike fruit yield, weekly shoot yield had a single peak at 9 WAP under 50% shading and two peaks under full irradiance (8 and 11 WAP) (Figure 2B).

SHP also produced fruits; and the fruit matured at 9 WAP in both shading treatments. In this case, SHP produced one-third of the fruit weight of FHP. The fruits were positioned at rest of the branches. The rest of the branches included leftover base of harvesting shoot, hard stems and short shoots that were not suitable for the shoot harvesting. In total, plants in full sun produced 235.6 g of fruits from 79 clusters, whereas plants from 50% shade produced 71.0 g fromm 20 clusters.

Table 2. Time to harvest and yield of *S. nigrum* grown in full sun and 50% shading harvested for shoots and fruits

Parts harvested	Shading (%)	First harvest time (WAP)	Monthly yield (g)	Total yield (ton.ha^{-1})	Total income^{z} (US\$.ha^{-1})
Shoot	0	5	70.4±2.6	3.51±0.13	1253.60
	50	5	39.0±6.8	1.95±0.34	696.40
		ns	*	*	-
Fruit	0	6	242.9±98.0	11.13±4.49	2385.00
	50	7	113.2±18.7	5.19±0.85	1112.10
		*	ns	ns	-

Note: values are mean±S.D; WAP: week after planting; *: significantly different at t-test α 5%, ns: not significantly different.
^{z}IDR 5000 per kg of shoots and IDR 3000 per kg of fruits (1 US$=IDR14,000); - : not applicable for statistical analysis.

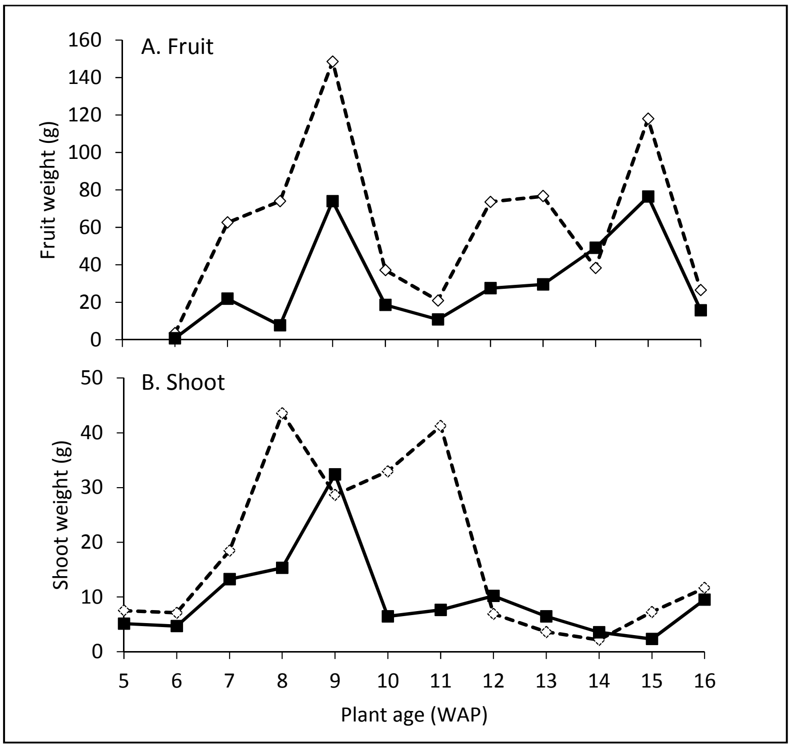

Figure 2. Weekly shoot yield of *S. nigrum* grown under full sun and 50% shading. A: fruit yield; B: shoot yield. Unfilled and filled square symbols represent full sun and 50%, respectively.

Biomass Partition

Destructive analysis at 16 WAP showed no significant difference among the shade treatments and the harvesting methods on the number and fresh weight of leaf, except dry leaf weight of FHP (Table 3). FHP under 50% shading treatment produced lower leaf dry weight as compared to those under full irradiance. There was no significant effect of the different level of shadings on the fresh and dry weight of the stem in the different harvesting methods. In contrast to FHP, stem fresh and dry weight from SHP tend to increase by shading treatment.

Regarding root characters, our results showed that the different shade levels had significant effects on root dry weight as shown in Table 4. It was expected that the root dry weight of the FHP was lower under 50% shading. Significant suppression on root dry mass of the FHP under 50% shading is presumably due to the fruit fruits are stronger sink as stated by Ferre et al. (2009). However under 50% shade condition, SHP tended to have longer roots (Table 4). This may be due to the shoot harvesting which may have slightly stimulated root growth resulting in a longer life of *S. nigrum* under the shade condition.

Shade treatment did not change the canopy to root ratio in both harvesting methods (Table 4). However, SHP had a 10% lower ratio of shoot to root in 50% shading

Table 3. Leaf and stem weight of *S. nigrum* grown in full sun and 50% shade harvested for shoots and fruits at 16 WAP

Parts harvested	Shade (%)	Leaf			Stem	
		Number per plant	FW (g)	DW (g)	FW (g)	DW (g)
Shoot	0	129±38	16.2±5.6	2.2±0.6	73.8±36.5	13.2±2.1
	50	123±108	14.3±10.2	2.0±1.7	105.7±22.3	16.7±7.2
		ns	ns	ns	ns	ns
Fruit	0	351±153	60.3±18.6	9.5±3.5	205.8±89.1	46.0±19.8
	50	202±104	48.0±34.9	5.5±2.7	174.5±12.8	23.7±3.3
		ns	ns	*	ns	ns

Note: values are mean±S.D; * significantly different at t-test α 5%; ns: not significantly different; FW: fresh weight (g); DW: dry weight (g).

Table 4. Root characters of *S. nigrum* grown in full sun and 50% shade harvested for shoots and fruits at 16 WAP

Parts harvested	Shade (%)	Number of roots	Root FW (g)	Root DW (g)	Root Length (cm)	Shoot to root ratio
Shoot	0	14±7	12.5±5.8	3.8±0.8	15.3±5.5	4.01±0.59
	50	20±11	24.8±2.8	5.2±0.3	28.0±18.1	3.60±1.02
		ns	ns	ns	ns	ns
Fruit	0	20±3	39.0±9.8	14.0±3.3	22.8±2.6	3.85±0.83
	50	21±6	20.2±2.4	5.5±0.5	19.8±5.2	5.34±0.66
		ns	ns	*	ns	ns

Note: values are mean±S.D; *significantly different at t-test α 5%, ns: not significantly different; FW: fresh weight (g); DW: dry weight (g); RL: root length (cm).

treatment; otherwise the ratio of FHP increased by 25.3%. The change in ratio may indicate a different mode of assimilate allocation. Shoot harvest on one side reduced the source capacity, but the rest of the leaves were presumably able to maintain optimum condition for photosynthesis as indicated by a lower percentage of senesced leaves than those of FHP.

Regardless of treatments, the proportion of *S. nigrum* stem biomass was 66.2 to 69.9%, roots 15.9 to 21.7% and leaves 8.4 to 15.9% of total biomass (Figure 3). In FHP, about 16% of biomass was allocated for roots under 50% shading and about 20% under full irradiance. It is likely that under 50% shading *S. nigrum* allocated more assimilates to canopy than to roots in FHP, whereas in SHP more assimilates were allocated to roots.

Shading had decreased the yield of FHP and the yield was higher in the FHP than the SHP. In addition, FHP had a shorter lifespan than SHP and it is likely that longer life span in SHP could be one of the farmers' considerations to maintain *S. nigrum* in intercropping or mixed cropping systems in central Java. The longer availability of leaves under shade conditions is likely the reason for farmers in Java to maintain *S. nigrum* as a perennial crop in an intercropping system. Conversely, farmers who grow *S. nigrum* in monoculture and full sun in west Java will benefit from high fruit yields (Table 2).

Regarding the preference for harvesting the shoots or the fruits, Grigsby-Toussaint et al. (2010) noted that cultural experience and availability determine the plant utilization method. It is possible that the Sundanese, who are known to consume raw vegetables as salad (https://en.wikipedia.org/wiki/Sundanese_people), accept the *S. nigrum* fruit unlike Javanese. As bitterness is one of the genetic properties of Solanaceae (Cárdenas et al., 2015), it is possible that bitterness of *S. nigrum* leaves is not acceptable for raw consumption by the Sundanese. On the other hand, both SHP and FHP grown under shading tend to have more attractive leaves due to lower pests and disease infections. Low disease infection in tomato under shading has been reported (Kittas et al., 2009; Peet, 2009). Disease incident on *S. nigrum* leaves in open field has been reported (Putriantari and Santosa, 2014). In this study, the common pests found on *S. nigrum* leaves under

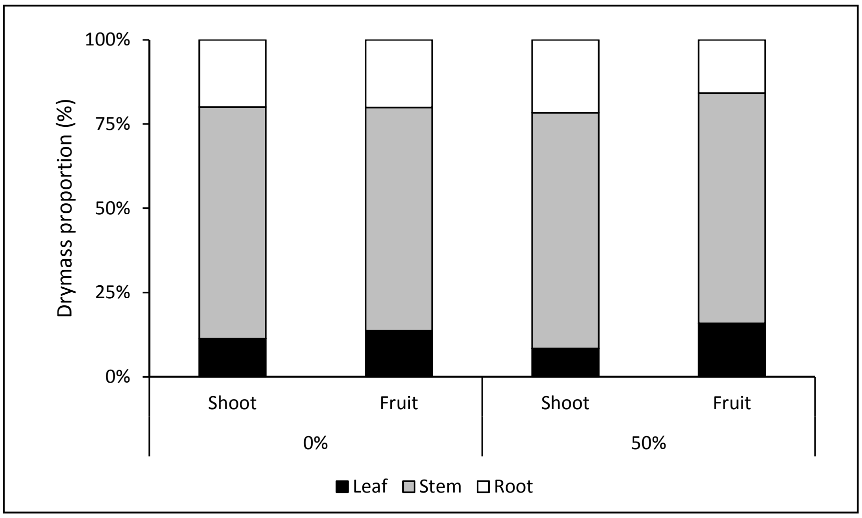

Figure 3. Proportion of dry mass of *S. nigrum* plants in full sun and 50% shade harvested for shoots and fruits.

full irradiance were aphids, caterpillar, ladybug and mites. According to Carnot et al. (2017), aphids suck the sap of young leaves, causing malformation on leaf morphology. Caterpillars seemed to be a general pest in both shading treatments, but there were more plants affected by the caterpillars in the open field compared to those in the shades. Ladybugs and caterpillars were rarely found in SHP, unlike in FHP in both shading treatments; meaning that the leaves from SHP was more marketable, and this could be an additional consideration by the Javanese to harvest the leaves.

Conclusion

Fruits and shoots of *S. nigrum* can be harvested from plants grown in full and 50% shade, but yields were higher under full sun than under the shade. *S. nigrum* plants in shades, however, grew better and healthier as indicated by lower pest and disease infections, and had a longer life span. In this context, parts of the plants to be harvested are likely related to different yields from different farming methods. Thus, preference of Sundanese farmers to harvest fruits and Javanese to harvest shoots may be related to the traditional heritage of the cultivation practices. It implies that both monoculture and intercropping methods are suitable for *S. nigrum*.

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