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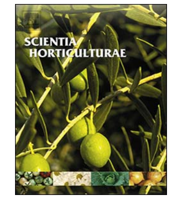

Enhancing growth and leaf yield in *Gynandropsis gynandra* (L.) Briq. (Cleomaceae) using agronomic practices to accelerate crop domestication

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ABSTRACT

Gynandropsis gynandra (Spider plant) is an African leafy vegetable with several nutritional benefits, considered as a weed or cultivated crop. The species is of interest for local communities though knowledge on agronomic practices need to be improved. This study assessed the effects of two seedling ages at transplanting (two weeks and three weeks after sowing), three planting densities (444,444; 250,000 and 166,666 plants ha^{-1}), three second harvest timings (one week, two weeks and three weeks after the first harvest) and three cutting heights ($\leq$10 cm; between 10 and 15 cm and $\geq$15 cm) on growth and yield in *Gynandropsis gynandra*. The results revealed that two weeks and three weeks old seedlings could be used for the species cultivation. Seedling age, planting density and consecutive cutting time had significant effects on growth and biomass yield. Increasing planting density decreased plant growth but increased edible biomass yield. Planting density of 444,444 plants ha^{-1} gave the highest biomass yield (29 t ha^{-1}). Cutting height greater than 15 cm favored a better regrowth and higher biomass yield. Harvesting plants two weeks after the first harvest gave more biomass yield but yield decreased from the first harvest to the second one. These results offer new insights into horticultural practices and the expanding of spider plant cultivation in urban and periurban areas.

1. Introduction

Traditional leafy vegetables including *Gynandropsis gynandra* (Spider plant) contribute better to the balance of micronutrients in the diets of local populations (Schönfeldt and Pretorius, 2011; Smith and Eyzaguirre, 2007; van Jaarsveld et al., 2014). They reduce more efficiently hidden hunger and malnutrition than major crops like cereals, pulses, tubers (Yang and Keding, 2009). They are also adapted to local agro-ecological conditions and constitute a prime source of income mainly for rural populations. However, most of those African traditional leafy vegetables have been neglected and underutilized since they have been viewed as the poor man's food (Padulosi et al., 2013). This perception has been quickly changing and there is an increasing interest in African leafy vegetables. Consequently, in *Gynandropsis gynandra* for instance, there are growing research efforts to document agronomy (Gonye et al., 2017; Onyango et al., 2016) and achieve breeding (Omondi et al., 2017a; Wu et al., 2017).

Gynandropsis gynandra thrives in Africa and Asia where it grows abundantly during the rainy season. The species is found near human settlements or roadsides in wild populations but also cultivated in home gardens or in urban and periurban agriculture (Achigan-Dako et al., 2010; Chweya and Mnzava, 1997; Kiebre et al., 2015; Mnzava and Chigumira, 2004; Weinberger and Pichop, 2009). In Eastern and Southern Africa, the species is cultivated and sold in urban markets and supermarkets (Schippers, 2004) but also grows as a weed. In Zimbabwe, *Gynandropsis gynandra* is the most edible weed used by the local communities (Maroyi, 2013). In Eastern Cape Province, South Africa, the species is still regarded as wild (Sowunmi, 2015), while in the rural areas of Limpopo in South Africa, *G. gynandra* is collected from wild but also cultivated and sold (Faber et al., 2010). In West Africa, the species is spontaneous and widely collected but also cultivated by local communities in home gardens (Achigan-Dako et al., 2010; Kiebre et al., 2015).

The species is reported to contain high values of minerals including potassium, calcium, magnesium, phosphorus, iron, manganese and zinc (Koua et al., 2015; Omondi et al., 2017b; van Jaarsveld et al., 2014). *Gynandropsis gynandra* is also a rich source of vitamin C, vitamin A, vitamin B1, vitamin B2, vitamin B9, β-Carotene and proteins (Neugart et al., 2017; Schönfeldt and Pretorius, 2011; van Jaarsveld et al., 2014). Increased consumption of the species will be beneficial for human health.

Up-scaling the production of *Gynandropsis gynandra* requires the

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development of adequate agronomic practices for yield improvement (Onyango et al., 2013). Agronomic practices include planting density, fertilization, pest management, sowing or transplanting date, stage of transplanting (Momoh and Zhou, 2001), irrigation and harvest techniques that affect crop yield. For instance, transplanting time and planting density were raised as important factors affecting onion productivity (Caruso et al., 2014) and cabbage yield under plastic mulch (Paranhos et al., 2016). Investigations on agronomic practices in *G. gynandra* mostly focused on the effect of fertilizer and deflowering in growth, leaf yield and nutrient content (Garjila et al., 2017; Gonye et al., 2017; Masinde and Agong, 2011; Mauyo et al., 2008; Mavengahama, 2013; Mutua et al., 2015; Seeiso and Materechera, 2012; Wangolo et al., 2015). Application of high dose of nitrogen fertilizer (300 kg ha^{-1} of NPK, 300 kg ha^{-1} of Lime ammonium nitrate) combined with daily deflowering increased leaf yield (Mavengahama, 2013; Mutua et al., 2015). Those doses may not be standard while optimal nitrogen dose depend on soils conditions and seasons (Masinde and Agong, 2011). However, other agronomic practices such as planting density, harvesting frequency and techniques, cutting height, irrigation, planting date are less investigated.

Diverse plant spacing has been recommended for the species and include 30–50 cm between rows and 15–20 cm within rows (Oluoch et al., 2009). In South Africa, it was recommended to use 30 cm as inter-row spacing and 10–15 cm between plants (Department of Agriculture Forestry and Fisheries, 2014). Moreover, people from Adja communities in Southern Benin broadcasted seeds on the plots showing no specific planting density (Matro, 2015). In 2004, AVRDC recommended 20 cm × 20 cm. Wangolo et al. (2015) included planting density (30 cm × 20 cm, 30 cm × 15 cm, 20 cm × 15 cm) as factor in their study but did not show the effect of this factor. This situation may be explained by the sowing method currently used which is direct sowing. Direct sowing is made by spreading the seeds in rows and thinning is done three weeks later to have planting spacing. With this, it is clear that there is a need to assess the effect of planting density in order to recommend a strong one.

Transplanting allows selection of vigorous seedlings in horticultural crops and may not be suitable for all species. For most leafy vegetables, it is recommended to transplant seedlings at three weeks after sowing in nursery. In *Gynandropsis gynandra*, transplanted plants increased leaf yield than direct seeding (Orchard and Ngwerume, 2009). However, transplanting is not common in *Gynandropsis gynandra* (Mnzava and Chigumira, 2004) and was attributed to the root systems. The root systems consists of long taproot with few secondary roots and slow production of new roots (Chweya and Mnzava, 1997; Mnzava and Chigumira, 2004). In spite of that the species could into some extent well respond to transplanting while roots established by direct seeding plants differ from that developed by transplanted seedlings (Leskovar and Stoffella, 1995). For instance, in pepper (*Capsicum annuum* L.) taprooted species, strong tap root observed in direct seeding plants was modified into lateral and basal roots in transplanted plants (Leskovar et al., 1990; Leskovar and Stoffella, 1995) which allow seedlings to easily grow. The ability of seedlings to overcome shock during transplanting depends on the amount of roots retained during the transplanting, water absorption capacity of the retained roots and the rate of new root formation as well as soil moisture (Leskovar and Stoffella, 1995; Sadhu, 1989).

In leafy vegetable production, harvesting practices including cutting, defoliation (picking individual leaves or leafy branches at frequent intervals), uprooting whole plant, topping (pinching/deflowering) also affect crop yield (Chweya and Mnzava, 1997; Grubben, 1975; Nono-Womdim et al., 2012; Ojo, 2001). In *Gynandropsis gynandra*, leaves are harvested by cutting every week (Seeiso and Materechera, 2012) or two weeks (Machakaire et al., 1998). There is no comparison of leaf yield for consecutive cutting though the effectiveness of cutting depends on its frequency and height, which can affect the regrowth and hence the yield of the species. To accelerate the domestication of *Gynandropsis gynandra*, it is crucial to improve our knowledge of the effects of planting density, transplanting time and cutting modes on the yield.

This study aims at improving the production of *Gynandropsis gynandra* by developing the most suitable agronomic practices. Specifically, the study assessed: (i) the effects of seedlings age and planting density on the growth and biomass yield in *Gynandropsis gynandra*, and (ii) the effects of cutting height and second harvest timing on regrowth and biomass yield in *Gynandropsis gynandra*. To achieve those specific objectives, we hypothesized that: (i) growth and biomass yield in *Gynandropsis gynandra* decrease with increasing seedling age and planting density; and (ii) cutting height and second harvest time affect regrowth and biomass yield in *Gynandropsis gynandra*.

2. Materials and methods

2.1. Experimental site and plant material

The study was conducted at the experimental site (6°25′00.8″N, 2°20′24.5″E) of the Laboratory of Genetics, Horticulture and Seed Science (GBioS) of the Faculty of Agronomic Sciences (FSA), University of Abomey-Calavi (UAC) during the short rainy season from September 2015 to December 2015. Two independent experiments were implemented, the first experiment from September 2015 to November 2015 and the second one from October 2015 to December 2015. The soil type was ferralitic (Azontondé, 1991; Willaime and Volkoff, 1967). Prior to the experiments, soil samples from 0 to 20 cm depth were analyzed at the Laboratory of Soil Science at the Faculty of Agronomic Sciences, University of Abomey-Calavi for its physico-chemical properties. The soil consisted of 61.98% sand, 25.75% silt and 12.27% clay with pH (KCl) of 5.48 and pH (H_2O) of 5.88. Soil texture was sandy-loam and the percentages of organic carbon and nitrogen (N) were 1.03% and 0.06%, respectively. The soil contained 23.06 mg kg^{-1} of available phosphorus, 811.2 mg kg^{-1} of available potassium, 287.95 mg kg^{-1} of magnesium and 126 mg kg^{-1} of calcium. Soil drainage and permeability were good. The experimental site belongs to the Guinean area with a bimodal rainfall. The annual rainfall was 1,000 mm in 48 days with a mean temperature of 27 °C and a relative humidity up to 80%. Data on climate conditions during the experiments (Table 1) were obtained from the meteorological station of the International Institute of Tropical Agriculture (IITA), Abomey-Calavi, Benin, located at 1 km to the experimental site. During the experiments, the daily average temperature, relative humidity, and solar radiation were 26.91 °C, 82.89% and 15.97 MJ m^{-2} respectively. The total rainfall was 220.6 mm during the experimental period with higher precipitation in October. The water evaporation was low in October and increased over the time with a total of 481.97 mm from September to December 2015.

Table 1
Total rainfall and evaporation, daily average temperature, solar radiation, and relative humidity in Abomey-Calavi from September to December 2015.

Month (in 2015)	Total rainfall (mm)	Total evaporation (mm)	Average solar radiation (MJ m^{-2} day^{-1})	Average temperature (°C)	Average relative humidity (%)
September	87.80	105.01	13.13	26.31	89.38
October	110.50	102.44	16.24	27.04	88.23
November	22.30	117.33	17.86	27.74	86.65
December	0	156.89	16.66	26.56	67.33