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Improving French Bean (*PhaseolusVulgaris* L.) Pod Yield and Quality Through the Use of Different Coloured Agronet Covers

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Abstract

French bean (*Phaseolus vulgaris* L.) is among important vegetables in supplying proteins, vitamins, minerals and dietary fiber to humans worldwide. Its successful production in the tropics is, however, constrained by abiotic and biotic stresses as the crop is predominantly grown in open fields. Netting technology has been proved successful in protecting crops against adverse weather and insect pests. Coloured net technology is an emerging technology, which introduces additional benefits on top of the various protective functions of nettings. Two trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Kenya to evaluate the effects of different coloured agronet covers on growth, pod yield and quality of French bean. A randomized complete block design (RCBD) with six treatments and four replications was used. French bean plants were grown under a white, blue, yellow, tricolour or grey net cover with open field production as the control. Variables measured included days to emergence and emergence percentage (%), stem collar diameter, plant height, number of branches and internodes, internode length and crop yield. French bean grown under the different coloured net covers showed relatively better growth and crop performance marked by more pods and higher total yields and percentage of marketable yields compared to those grown in the open field. Growing French bean under net covers hastened the rate of pod maturation more-so under the light-coloured colour-nets. Findings of this study demonstrate the potential of coloured net covers in improving French bean pod yield and quality under tropical field conditions.

Keywords: Snap bean, Green bean, Modified environment, yield, pod quality

1. Introduction

French bean (*Phaseolus vulgaris* L.) is grown by both large and small holder farmers in East Africa and Africa in general (Center for International Agricultural Technology [CIAT], 2006). Total world production exceeds 17 million tonnes, with China, Indonesia, Turkey, India and Egypt among the largest producers and consumers of the crop (Food and Agriculture Organization Corporate Statistical Database [FAOSTAT], 2010). The crop is a major export vegetable in Kenya and ranks second to cut flowers in terms of foreign exchange earnings generated from the dynamic horticultural sub-sector (Horticultural Crops Development Authority [HCDA], 2011). Much of Kenyan French bean is intensively grown by small scale farmers (Ndegwa *et al*., 2010) mainly for fresh export and as a source of family income (Monda, Ndegwa, & Munene, 2003). French bean is an important crop in the social economic systems and livelihoods of many Kenyans supporting people directly or indirectly (Odero, Mburu, Ogutu, & Nderitu, 2012). Moreover, the immature pods are an important food source in many parts of the world supplying protein (Arulbalachandran & Mullainathan, 2009), vitamins, minerals and dietary fibre (Kelly & Scott, 1992). The crop is also important for its nitrogen fixing capability (Amannuel, Kiihne, Tanner, & Vlek, 2000) and can be used in crop rotation systems to improve soil conditions.

Despite the economic importance and potential of French bean in addressing food insecurity, improving incomes and alleviating poverty, low yields remain a common scenario with most growers in many sub-saharan countries. As low as 6 to 8 tonnes per hectare of French bean have been realised in Kenya (Wahome, Kimani, Muthomi, & Narla, 2013), compared to 15 to 20 tonnes per hectare recorded in developing countries in South America and south East Asia (Wahome *et al*., 2013). Throughout its production cycle, French bean is subject to many abiotic and biotic stresses including erratic rainfall, prolonged dry spells and heavy infestation by insect pest, which present major challenges to French bean growers particularly in the tropics as the crop is predominantly grown in open fields. French bean yield losses due to insect pests alone have been estimated to range from 35% to 100% annually (Singh & Schwartz, 2011) while drought stress can cause more than 50% yield loss (Zlatev & Lidon, 2012).

A number of simple technologies have been tested in different parts of the world and proved successful in protecting crops against adverse weather conditions and insect pests. Netting technology has been used in agriculture to protect crops against environmental hazards like excessive solar radiation, wind, hail and flying insects and improve plant microclimate through reduction in heat/chill, drought stresses, and moderation of rapid climatic stresses leading to improved crop yield and quality (Shahak, Gussakovsky, Cohen, & Lurie, 2004). The use of net covers in crop production offers a cheaper and less energy consuming technology than greenhouses (Shahak, 2008). Coloured net technology is on the other hand, an emerging technology, which introduces additional benefits on top of the various protective functions of nettings. Photoselective nets which include the coloured nets are unique in that they both spectrally-modify as well as scatter the transmitted light, absorbing spectral bands shorter or longer than the visible range. Spectral manipulation has a potential for promoting physiological responses in plants while the scattering of light improves penetration into the inner canopy, all of which contribute towards better crop performance (Rajapakse & Shahak, 2007). Different crops respond differently to the spectral manipulation induced by different colours of net covers. Evaluations to identify ideal net colour(s) that maximize French bean pod yield and quality are therefore imperative for better exploitation of the potential of the crop as a food and income source for the rural populations. This study therefore aimed at determining the effects of different coloured agronet covers on growth, pod yield and quality of French bean.

2. Materials and Methods

2.1 Experimental Site Description

The study was conducted at the Horticulture Research and Teaching Field of Egerton University, Njoro, Kenya. The field lies at latitude of 0°23′ S and longitude 35°35′ E in the Lower Highland III Agro Ecological Zone (LH3) at an altitude of ≈2238 m above sea level. The soils are predominantly vitric mollic andosols with a pH of 6.0 to 6.5 (Jaetzold & Schmidt, 2006). The site mean temperature and rainfall during the study period are presented in Table 1.

Table 1. Average monthly air temperature (^oC) and precipitation (mm) during French bean production over the two trials (July to Oct. 2015 and Nov. 2015 to Feb. 2016)

	Trial 1				Trial 2			
	July	August	September	October	November	December	January	February
Air temperature	20.2	20.8	21.7	21.2	19.1	20.2	20.6	22.0
Precipitation	53.4	41.6	85.7	90.31	198.8	82.9	86.6	23.4

Source: Egerton University Engineering Department (2016)

2.2 Planting Material, Experimental Design, and Treatments

French bean seeds of cultivar Source [Amiran (K) Ltd., Nairobi, Kenya] were used. ‘Source’ is a determinate variety and one of the most popular among the French bean growers in Kenya. The experiment was laid out in a Randomized Complete Block Design (RCBD) with six treatments replicated four times. The treatments comprised of growing French bean under white net, blue net, yellow net, tricolour net, grey net, and open field (control). The tricolour net was predominantly white in colour with blue and yellow stripes. The agronets used are made from high-density polyethylene fully recyclable monofilament of 100 denier knitted into a mesh with 0.9 mm x 0.7 mm average pore size. They are ultraviolet protected for extended shelf life. They were obtained from A to Z Textile Mills Ltd., Arusha, Tanzania.

Each trial covered an area of 20.5 m by 11 m with individual blocks measuring 20.5 m by 2 m separated by a 1 meter buffer. Individual experimental units within a block measured 3 m by 2 m with an inter-plot spacing of 0.5 m. On net covered treatments, poles 75 cm long and ≈ 5 cm thick were installed before planting to provide support for the net covers. The poles were driven 25 cm into the ground at each corner and at the center of the plot to anchor the agronets. Agronets were then mounted completely covering the plots and pegged at each corner to minimize wind interference. Once covered, plots were maintained permanently covered and only opened during routine plant management and data collection periods.

2.3 Data Collection

Data collection commenced from the start of seedling emergence and continued to the last harvest.

2.3.1 Days to Emergence and Emergence Percentage

The number of days from sowing to first emergence of French bean in the different experimental units were monitored and recorded. Thereafter, seedling numbers were counted at a two-day interval for a period of one week and progressive emergence percentages computed for each treatment using the formula:

$$\frac{\text{Number of emerged seedlings}}{\text{Number of seeds sown}} \times 100\% \qquad (1)$$

2.3.2 Plant Growth Variables

Four plants from the inner rows of each experimental unit were randomly selected and tagged for collection of plant growth variables data. In this study, plant growth variables measured were stem collar diameter, plant height, number of branches and internodes and internode length. Plant growth data were collected on a weekly basis beginning 21 Days after Planting (DAP) to first harvest. During each data collection date, stem collar diameter of the four tagged French bean plants was measured at ≈ 4 cm from the ground level using a digital vernier caliper (Model 599-577-1/USA) and data obtained used to compute the average stem collar diameter of plants for the different treatments in millimeters (mm). Height of each tagged plant was also measured in centimeters (cm) using a meter ruler from the ground level to the point of growth and the number of internodes and branches counted and recorded as number of branches or internodes per plant (no. /plant). Thereafter, the length of each internode on the main stem was measured using a ruler and data obtained used to compute the average internode length of the plants in cm.

2.3.3 Yield

Harvesting began at 62 DAP. The crop was harvested thrice per week for a period of four weeks removing pods that had attained horticultural maturity during each harvest. At each harvest, the pods harvested from each tagged plant were separately counted and the number of pods obtained recorded and later used to compute the average number of pods per plant (no./plant). The pods were then weighed using a weighing balance (Advanced Technocracy Inc. Ambala) and weight obtained recorded in grams (gms) and later used to compute the average pod weight per plant for the individual treatments. Thereafter, a composite sample was made from the harvest of tagged plants of each experimental unit, 100 gms of fresh pods drawn from the sample, oven dried at 70^{o}C to a constant weight and the dry weight determined in gms which was later used in the computation of total plant biomass.

French bean pods harvested from each experimental unit were then separately sorted as marketable and non-marketable. Non-marketable pods included the overgrown pods, off type, those damaged by pest or disease and those with physical damage or physiological defects. Marketable French bean pods were then graded based on pod sizes as extra fine grade, fine grade and bobby beans according to the French bean grading system (HCDA, 2011). The weight of each grade was then measured and recorded as weight in grams per grade per treatment.

Total plant biomass was determined at three different plant growth stages; at the trifoliate leaf, flowering and podding stage using four plants from each experimental unit. The plants were dug out recovering most of the roots, cleaned and oven dried at 70^{o}C to constant weights and their dry weights determined. The data obtained were used to compute the average total biomass per plant as;

$$\text{Total Biomass (g DW/plant)} = \frac{\text{Total Plant Biomass} + \text{Total Pod Dry Weight}}{4} \qquad (2)$$

Where; Total pod dry weight was computed by multiplying pod dry weight of the 100 grams of fresh pods drawn from the composite sample for biomass determination at each harvest by the total fresh weight obtained for the individual treatments at that harvest.

2.4 Data Analysis

The Proc univariate procedure of SAS (Version 9.1; SAS Institute, Cary, NC) was used to check for normality of the data before analysis. Data were then subjected to analysis of variance (ANOVA) using the GLM procedure of SAS at $P \leq 0.05$. Data were analyzed using the statistical RCBD model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \qquad (3)$$

Where; Y_{ij} is the French bean response, μ is the overall mean, α_i is the effect due to the i^{th} treatment, β_j is the effect due to the j^{th} block, $\varepsilon_{ij}$is the random error term. Means for significant treatments at the F test were separated using Tukey's honestly significant difference (THSD) test at $P \leq 0.05$.

3. Results

3.1 Effects of Colour of Agronet Cover on Days to First Emergence and Emergence Percentage

French bean seedling emergence was enhanced by use of the different coloured agronet covers (Table 2). Regardless of the colour of agronet cover used, seedling emergence occurred earlier under net covers compared to under open field production. The first seedling emerged 5 DAP under all net covers compared to after 7 DAP under the control treatment. Percent seedling emergence was also influenced by the use of agronet covers especially at the early days of emergence up to 7 DAP when percent emergence of seedlings was significantly higher under agronet covers compared to the control treatment. There was no significant difference in percent seedling emergence noted among the different coloured agronets during these sampling dates (Table 2). Beyond 7 DAP, percentage seedling emergence remained higher under the net covered treatments although the differences with the control treatment were not significant. On overall, the highest and lowest germination percentage of 81.29% and 76.21% was obtained under the blue and yellow net covers, respectively by the final day of data collection

Table 2. Effects of colour of agronet cover on days to first emergence and percent emergence of French bean during production

	Day after Planting			
Treatment	5	7	9	11
White	3.4a*	58.1a	75.4**	79.5
Yellow	2.6a	51.6a	72.6	76.2
Tricolour	4.3a	53.3a	74.0	78.7
Grey	2.2a	47.6a	73.1	78.5
Blue	3.4a	56.3a	77.0	81.3
Control	0b	22.2b	66.8	76.3

*Means followed by the same letter within a column are not significantly different according to Tukey's honestly significant difference test at $p \leq 0.05$.

**Means within a column not followed by a letter are not significantly different according to F-test at $p \leq 0.05$.

3.2 Effects of Colour of Agronet Cover on French bean Plant Growth

Regardless of the colour of agronet cover used, French bean plants showed relatively better growth under net covers than under the control treatment (Table 3). French bean plants grown under the white, yellow, grey and tricolor net covers had significantly larger collar diameter in all sampling dates compared to control plants. Collar diameter recorded for plants grown under the blue net was also slightly higher than that for control plants, although the difference among the two treatments was not significant in most sampling dates. Among the net covered treatments, plants under white cover had the thickest stems followed by those under tricolour cover, then those under grey cover, followed by those under the yellow cover, with the thinnest stems obtained under the blue net cover.

Growing French bean under net covers also improved plant height compared to control plants. In all sampling dates, plants were tallest under the yellow net cover and shortest under the control treatment. Among the other treatments, plants tended to be taller under the grey net cover followed by those under the blue net cover, then those under tricolour net and shortest under the white net cover in most sampling dates. The use of agronet covers also improved on the plant branching ability regardless of the colour of the net cover used. The number of branches per plant was significantly higher for plants grown under all net covers compared to control plants at all sampling dates except for plants grown under blue cover at the final sampling date (56 DAP). Up to 49 DAP, the number of branches per plant was not significantly different among the different net covers used. However, by56 DAP, the number of branches per plant was significantly higher for plants grown under the white cover compared to those under the blue cover. Among the other net covers, plants grown under the tricolour cover also tended to have slightly more branches at the later stages of plant growth (49 and 56 DAP) compared to those grown under yellow, grey and blue covers.

Table 3. Effects of colour of agronet cover on the growth of French bean during production

Treatment	Days after Planting					
	21	28	35	42	49	56
Collar diameter (mm)						
White	2.75a*	3.37a	4.09a	5.03a	5.74a	6.33a
Yellow	2.48bc	3.06bc	3.72bc	4.42bc	5.06bc	5.60bc
Tricolour	2.66ab	3.32a	4.00ab	4.86ab	5.48ab	6.06ab
Grey	2.54abc	3.15ab	3.82ab	4.53b	5.21b	5.80b
Blue	2.35cd	2.92cd	3.44cd	4.05cd	4.68cd	5.24c
Control	2.21d	2.80d	3.27d	3.84d	4.22d	4.69d
Plant height (cm)						
White	6.08c	9.01c	12.85c	21.70b	29.29b	35.17b
Yellow	7.91a	12.86a	21.12a	34.01a	40.69a	46.88a
Tricolour	6.48bc	9.74bc	13.88bc	22.86b	29.87b	36.14b
Grey	6.57bc	11.18ab	16.95b	25.90b	32.85b	38.74ab
Blue	7.09ab	10.16bc	14.81bc	23.80b	30.82b	36.88b
Control	4.89d	6.21d	7.77d	12.11c	16.18c	19.97c
Branches (no./plant)						
White	3.25a	5.22a	6.69a	7.69a	8.22a	8.69a
Yellow	2.97a	5.34a	6.34a	7.38a	7.63a	7.81ab
Tricolour	3.03a	4.97a	6.06a	7.28a	7.75a	8.34ab
Grey	3.00a	4.97a	6.06a	7.19a	7.66a	7.97ab
Blue	2.72a	4.53a	5.69a	6.75a	7.19a	7.50bc
Control	1.06b	2.88b	3.94b	5.25b	5.91b	6.63c
Number of internodes (no./plant)						
White	3.97a	5.44a	6.84a	7.84a	8.28a	8.47a
Yellow	4.03a	5.63a	6.75a	7.44a	7.69bc	7.81ab
Tricolour	3.91a	5.44a	6.75a	7.75a	8.03ab	8.19ab
Grey	3.91a	5.56a	6.66a	7.72a	7.94ab	8.00ab
Blue	3.84a	5.13a	6.31a	7.34ab	7.69bc	7.84ab
Control	3.25b	4.47b	5.75b	6.78b	7.34c	7.75b
Internode length (average/plant in cm)						
White	1.53c	1.65c	1.88d	2.76b	3.54b	4.16b
Yellow	1.96a	2.28a	3.11a	4.54a	5.27a	6.00a
Tricolour	1.66bc	1.79bc	2.06cd	2.95b	3.73b	4.42b
Grey	1.68bc	2.00b	2.52b	3.32b	4.12b	4.84b
Blue	1.85ab	1.98b	2.33bc	3.21b	4.00b	4.71b
Control	1.51c	1.39d	1.35e	1.78c	2.19c	2.57c

*Means followed by the same letter within a column and a parameter are not significantly different according to Tukey's honestly significant difference test at $p \leq 0.05$.

Plants grown under net covers also had significantly more internode numbers than control plants during the early stages of plant growth up to 35 DAP. At all sampling dates during this period, there were no significant differences in the number of internodes for plants grown under the different colours of net covers although plants under the white net cover tended to have slightly more internodes while those under the blue cover had the least number of internodes. Significantly more internodes were registered for plants grown under yellow, grey, tricolour and white net covers compared to internode numbers recorded for control plants at 42 DAP with no significant differences noted in internode numbers for plants grown under blue net cover and control plants. At 49 DAP, plants under the grey, tricolor and white net covers still registered significantly higher internode numbers than control plants with no statistical difference in internode numbers between plants grown under blue or yellow net covers and the control plants. By 56 DAP only plants under the white net were significantly different from control plants in internode numbers. Generally, plants grown without a net cover (control) had the lowest number of internodes throughout the study while among the net covered treatments, growing French bean under a blue net cover yielded plants with the lowest number of internodes during all sampling dates. Plants grown under net covers also had significantly longer internodes than control plants. During all sampling dates, internode length was longest under the yellow net and shortest under the control treatment. Among the net covers, plants grown under yellow net were significantly different from those under other net covers in internode length in all sampling dates except during the initial sampling date (21 DAP) when the internode length for plants grown under the blue net was not significantly different from that of plants grown under the yellow net cover. Internode length tended to be longer in plants under the grey net cover followed by those under the blue net cover, then those under tricolour net and shortest under the white net cover in most sampling dates.

3.3 Effects of Colour of Agronet Cover on the Yield of French bean

Growing French bean under the different coloured net covers improved the crop yield compared to open field production (Table 4). Regardless of the colour of the net cover used, plants grown under the net covers produced more pods per plant yielding higher total and marketable pod weights compared to control plants. On overall, the highest pod numbers per plant and total and marketable pod weight was obtained under the white net cover while pod numbers and total and marketable pod yields were lowest under open field production. Among the other treatments, plants under the yellow cover yielded better pod numbers and total and marketable pod weight while those under the blue net cover had the least pod numbers and total and marketable pod yields. There was no statistical difference in the number of pods per plant and total and marketable pod weight recorded for plants grown under the grey, tricolor and blue net covers. Growing the crop under the different coloured agronet covers substantially improved marketable French bean yields by between 42.0 – 103.3%. The highest increase in marketable pod yield of 103.3% was obtained under the white net cover while lowest increase of 42.0% was under the blue net covers. Growing French bean under the other net covers resulted in intermediate increase in French bean yield of 53.7% under the grey net cover, 56.3% under the tricolor net cover and 91.7% under the yellow net cover.

Table 4. Effects of colour of agronet cover on yield of French bean

Treatment	Pods/plant	Pod yield	Marketable	% increase in marketable yields
	no.	g/plant	g/plant	
White	87.47a*	132.55a	120.22a	103.3
Yellow	80.50ab	121.27a	113.23a	91.5
Tricolour	69.59ab	101.78ab	92.43ab	56.3
Grey	73.44ab	103.92ab	90.92ab	53.7
Blue	64.03ab	90.65ab	84.00ab	42.0
Control	53.38b	70.73b	59.14b	-

*Means followed by the same letter within a column and a parameter are not significantly different according to Tukey's honestly significant difference test at $p \leq 0.05$.

Growing the crop under the different coloured nets also showed some effect on the rate of pod maturation judged by the differences in the pod weight under the different pod grades (Figure 1). A higher percentage weight of marketable yields of French bean represented by extra fine pods was obtained under the blue net cover and control treatments compared to the other treatments while white and tricolour net covers registered lowest values of pods under the extra fine pod grade. On the other hand, higher fine grade pods were obtained under the white and tricolour net covers while the blue cover and control treatments registered lowest values of fine grade pod with the yellow and grey net covers registering intermediate values of pods under the extra fine and fine grades.

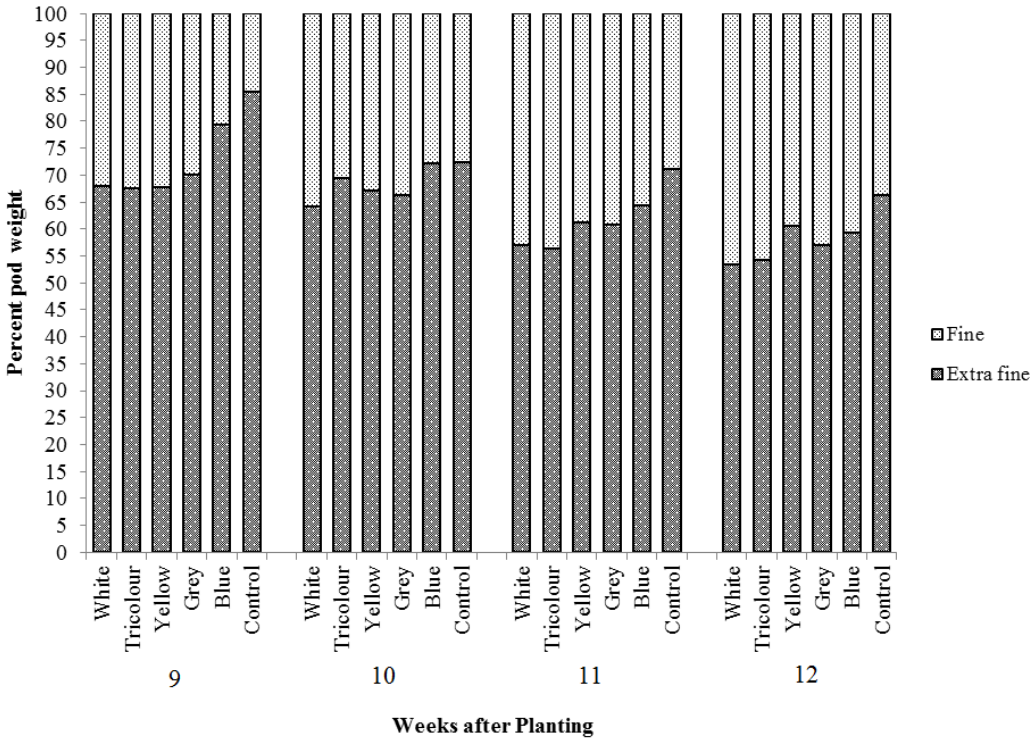

Figure 1. Effects of colour of agronet cover on weekly average percent pod weight per plant of the extra fine and fine French bean pods

Biomass production was also enhanced when French bean was grown under the different coloured net covers at all stages of plant growth compared to the control treatment (Table 5). During all the sampling dates, plants in the control treatment had the lowest total plant biomass while among the net covered treatments, biomass was lowest for plants grown under the blue net cover. At the early stage of French bean plant growth (trifoliate stage), plants under tricolour net cover had the highest plant biomass while at later stages of growth (flowering and podding stage) biomass was highest for plants grown under the white net cover. Total biomass for plants grown under the tricolour net cover was significantly higher than that of plants grown under the yellow and grey net covers at the trifoliate stage while at flowering and podding stage there was no statistical difference in plant biomass among the different net covers.

Table 5. Effects of colour of agronet cover on French bean total plant biomass (gms/plant)

Treatment	Trifoliate stage	Flowering stage	Podding stage
		g/plant	
White	1.46ab*	6.81a	30.22a
Yellow	1.24bc	6.44a	28.43ab
Tricolour	1.54a	6.67a	25.64ab
Grey	1.37abc	6.37a	23.97ab
Blue	1.12c	5.10a	20.46ab
Control	0.76d	2.77b	17.68b

*Means followed by the same letter within a column are not significantly different according to Tukey's honestly significant difference test at p≤0.05.

4. Discussion

Growing French bean under the different coloured agronet covers proved of potential benefit in French bean production. Regardless of the colour of agronet cover used, net covers advanced seedling emergence by two days and resulted in a higher percent emergence compared with the open field (control). Net covers have been reported to modify the immediate crop environment characterized by maintaining higher soil moisture content and air temperatures compared to open field conditions (Saidi, Gogo, Itulya, Martin, &Ngouajio, 2013; Gogo, Saidi, Ochieng, Martin, &Ngouajio, 2014). Adequate moisture and warmth are necessary conditions for activation of enzymes involved in seed germination (Raven, Ray, Evert, & Eichhorm, 2005). Moisture also ensures reduced resistance for the cotyledons of developing seedling as they move through the soil to reach the surface. These arguments lend support for the early and higher emergence registered under the different coloured net covers compared to open field production observed in the current study. Similar to the findings of the current study, Muleke, Saidi, Itulya, Martin, and Ngouajio (2013) observed early emergence and higher percent emergence of cabbage (*Brassica oleracea* var. *capitata*) seeds under net covered compared to open field nurseries. Among the different coloured net covers, final percent seedling emergence was highest under the blue net cover at 81.3% and lowest under the yellow net cover at 76.2% against a 76.3% emergence under the control treatment. Coloured shade nettings not only influence the microclimate to which the plant is exposed but also exhibit special optical properties to optimize desirable physiological responses of plants (Costa *et al*., 2010). Depending on the pigmentation of the plastic threads, coloured nets provide varying mixtures of natural unmodified light together with spectrally modified scattered light which improves light penetration into the inner canopy of plants as well as promotes specific photomorphogenetic and physiological responses in plants (Rajapakse & Shahak, 2007). Coloured shade nets absorbs spectral bands shorter, or longer than the visible light (Shahak*et al*., 2008). Differences in the final percent emergence of seedlings observed in the current study may be attributed to the differences in light intensity and quality under the different coloured nets marked by differences in the amount of filtered red, far-red or blue light by the different net covers. Yellow net covers have been documented to scatter more far-red light than red light thus decreasing the R/FR ratio (Goren, Alkalai-Tuvia, Perzelan, Fallik, & Aharon, 2011). On the other hand, R/FR ratio under blue net cover has been shown to be the same as under natural light (Oren-Shamir *et al*., 2001). According to Yerima, Esther, Madugu, Muwa, and Timothy (2012) seed germination is inhibited by far-red light and stimulated by red light while the effects of blue light cannot be reversed by far-red light possibly explaining the higher and lower final emergence percentages recorded for the blue and yellow net covers, respectively under the current study.

French bean plant growth in the current study was also enhanced by the use of net covers compared to open field production. Plants under net covers had more branches and internodes, longer internodes length, thicker and taller stems compared to those grown in the open. Net covers have been reported to improve crop performance as a result of modified and stabilized crop microclimate under the covers marked by lower diurnal temperature ranges and higher volumetric water content (Gogo *et al*., 2014) as well as reduced wind speed (Arthurs, Stamps, & Giglia, 2013). Besides the general advantages associated with net covers, colored nets selectively filter solar radiation to promote specific wavelengths of light (Arthurs *et al*., 2013), and increase light scattering which influences plant branching and crop compactness (Abul-Soud, Emam, &Abdrabbo, 2014). In the current study, plant growth variables were differently influenced by the different coloured net covers. Growing plants under the yellow net cover stimulated stem and internode elongation resulting in taller but slender French bean plants. Growing plants under the white and tricolour nets, on the other hand enhanced stem collar diameter and internode numbers, resulting in stout and compact plants while those under the blue net cover exhibited reduced stem collar diameter, branching and number of internodes. Longer and thin plants observed under the yellow net elicit elongation of stems at the expense of their thickness which can be attributed to reduction of R/FR ratio (Kasperbauer, 1994). Yellow net covers scatter more far-red light that penetrates into the plant canopy which stimulates internode and stem elongation (Goren *et al*., 2011). Far-red light promotes conversion of inactive gibberellins (GA) to active forms (Rajapakse, Young, McMahon, & Oi, 1999) which are potent promoters of stem elongation (Cummings, Foo, Weller, Reid, & Koutoulis, 2008) and regulate internode length in response to altered light condition (Maki, Rajapakse, S., Ballard, & Rajapakse, N., 2002). Despite having the highest internode numbers, plants under the white and tricolour (predominantly white) net covers tended to be shorter and bushy compared to plants under the other net covers which is attributable to the lower internode lengths recorded for plants under these treatments. According to Oren-Shamir *et al*. (2001), light transmitted through neutral-coloured nets is the same as the natural light but with consistently increased scattering over the natural light, making light reach a larger volume of the plant in a more homogenous way. Scattering of light may be as effective as manipulation of the light spectrum, in influencing the growth of plants (Nissim-Levi *et al*., 2008). Inhibition effects of blue net on plant growth were expressed in form of reduced internode numbers, branching and collar diameter of plants. Blue net covers substantially reduce radiation reaching the plant underneath (Abul-Soud*et al*., 2014) and the lack of RF or high R/FR ratio under blue net cover (Oren-Shamir *et al*., 2001) have been implicated as major inducers of reduced plant growth, possibly explaining the lower growth observed under blue net in the current study.

Better growth of French bean plants observed under the different net covers reflected in to higher total plant biomass and pod yields per plant compared to open field production. The higher biomass and pod yield obtained under net covers compared to control plants in the current study can be associated with the better plant development recorded under net covers possibly favoured by the modified microclimate under these treatments. Plants under net covers tended to be taller with thicker collar diameters and more branches depicting better biomass accumulation and providing a greater bearing surface and more stored food reserves for translocation to developing pods compared to control plants. Proper light distribution favours photosynthesis and metabolites translocation for better plant growth (Setiawati, Hasyim, Hudayya, & Shepard, 2014). Colour shade nets prevent excess sunlight and retain soil moisture for proper plant growth and productivity (Ilic, Milenkovic, Durovka, & Kapoutas, 2011). Better performance observed on plants under net covers could also be attributed to improved light compensation under net covers as a result of favorable microclimatic conditions (Nangare, Singh, Meena, Bhushan, & Bhatnagar, 2015). Growing French bean under net covers also substantially improved marketable yields of the crop. Marketable pod yield was 103.3% higher under the white net cover, 91.7% higher under the yellow cover, 56.3% higher under the tricolour net, 53.7% higher under the grey net and 42.0% higher under the blue net compared control plants. Better marketable yields obtained under net covers in this study can be attributed to enhanced pod production rates and reduced number of non-marketable pods due to reduced pest damage and physiological defects. Similarly, Ilic *et al*. (2011) reported higher export quality pepper fruit yield under coloured shade nets with pepper grown under the net covers resulting in a 113% to 131% increase in total fruit yield compared to open field.

Apart from total and marketable yields, the different coloured nets differentially affected the rate of pod maturation depicted by the proportion of marketable yield represented by extra fine and fine grade pods. The higher percentage of the weight of marketable yields of French bean represented by extra fine pods obtained under the blue net cover and control treatments indicates delayed pod maturation under these treatments compared to other treatments. On the other hand, more fine grade pods obtained under the white and tricolour net covers indicate enhanced rate of pod maturation under these treatments. Based on these findings, growing French bean under net covers and especially light-coloured covers hastens the rate of French bean pod maturation which can potentially reduce the harvest interval. Similar to these observations, Shahak*et al*. (2008) recorded advanced maturation of a number of table grape cultivars under light-coloured nets (pearl, white) compared to blue netting and open field growing which have now been incorporated by the growers for earliness and improved quality.

5. Conclusions and Recommendations

Results of the present study reveal growing French bean under the different coloured agronet covers as a useful technology for enhancing growth and pod yield and quality of the crop. With higher yields and better quality being the ultimate goal of every grower, we recommend the use of a white net cover in French bean production in regions with similar climatic conditions to those of the site of the current study. Studies combining the use of blue net covers early in the growing period and a white net cover soon after emergence are also recommended to establish whether both seedling emergence and growth and yields can better be optimized to enhance crop performance. We also recommend additional studies on the subject using different cultivars of French beans, other colours and mesh size of the net covers and in different agroecological zones to further validate the results. An analysis of the effect of the different colours of net covers on the sensory attributes and nutritive value of French bean pods would also be beneficial.

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