Growth and Morphology of Pea (*Pisum sativum* cv. Oregon sugar pod II) Plants grown Under Different Shading Screens at Hawassa, South Ethiopia

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Abstract

A field experiment was conducted in the dry seasons of (2016 and 2017) at Hawassa to assess the effects of three greenhouse-covering materials (Svensson with strip ventilation, white and yellow plastic films) on *growth and development of pea plants. Plants grown under the Svensson screen were 5.1– 6.4 cm taller, had 2–3 more internodes and the internodes were 0.44– 0.59 cm longer as compared to those grown under the yellow and the white plastic screens. However, no significant differences in dry matter or pod number were found between the screens. The difference in morphology was mainly due to the reduced transmittance of photosynthetic active radiation (PAR) and ultraviolet (UV) radiation of the Svensson as compared to the white and yellow plastic screens. Significantly smaller stomata aperture and lower leaf conductance were found on plants grown under yellow plastic film as compared to the imported screens. Thus, plants grown under yellow plastic film had 17% and 37% lower transpirational water loss as compared to the Svensson and the white plastic screens, respectively. Maximal PSII efficiency (Fv/Fm) was also lower in the locally produced yellow film as compared to the two imported screens, but Fv/Fm was not correlated with pod number. In conclusion, growth and development of pea are robust to changes in light climate. The cheap locally produced yellow plastic screen with relatively high PAR and UV transmittance is a suitable screen in the production of pea and as an efficient tool to control transpirational water loss in warmer regions like Ethiopia.*

Keywords: Growth, Greenhouse, Morphology, *Pea*, Plastic film, Light spectrum, transmittance

Introduction

Solar radiation consists of different types of wavelengths ranging from the shortest wavelength, ultraviolet (UV), to the longest wavelengths, near infra-red (NIR). Light is the most important climate factor affecting growth and development of plants as an energy source for photosynthesis and as a signal controlling a wide range of processes. Photosynthetic active radiation, PAR (400–700 nm) is the spectral range which plants are able to use for photosynthesis. Different parts of the solar spectrum controls different processes like seed germination, flowering and morphology (Chory *et al*., 1996). Light, along with other environmental clues like temperature, enables plants to adapt and adjust their growth and morphology to the environment. However, the response and sensitivity to the quantity and the quality of light differ widely among plant species (Tinoco-Ojanguren and Pearcy, 1995). Shade-tolerant plants often have lower photosynthesis rates, and they are subjected to photoinhibition when exposed to strong sunlight, as compared to sun tolerant species (Öquist *et al.*, 1992; Demmig-Adams *et al.*, 1998; Zhang *et al.*, 2004; Aleric and Kirkman, 2005).

Light quantity and quality can be manipulated to optimize plant production by adding light (Mortensen & Strømme, 1987; Olle & Viršile, 2013) or removing light and/or specific parts of the solar spectrum by the use of covering materials (Hemming *et al*., 2005; Krizek et al., 2005). The use of different covering materials, like colored nets and films to shade and/or to manipulate light quality is increasing in areas with excessive light; for example, near the equator. In addition to functioning as a method of providing shade (reduce PAR and temperature) and manipulating the light quality, the coverings are also used as a way to protect plants from diseases and pests (Antignus *et al.*, 1996; Díaz & Fereres, 2007). The response of a wide range of plants to a modified light environment created by colored films has been reported by different researchers (Li *et al.*, 2000; Li *et al.*, 2003). Plants like maize and sorghum tolerate high PAR, but under extreme sunny and warm conditions high transmission of PAR may cause high leaf temperatures and photoinhibition (Yakovleva and Titlyanov, 2001). High leaf temperatures can induce flower and fruit abortion in different plant species (Aloni *et al*., 2001; Guilioni *et al*., 2003; Marcelis , 2004).

Modifications of the UV part of the light spectrum have significant effects on growth and morphology of plants (Kittas et al., 1999; Terfa et al., 2014). UV absorbing films are widely used as cover material in protected cultivation (Antignus et al., 1996; Elad, 1997). White plastic coverings transmit UV radiation and can have positive effects on the intensity of rose flower color ,

and seed quality of pea (Luthria *et al*., 2006). However, the effects of these cover materials on crop behavior vary widely depending on species and cultivars (Mortensen & Strømme, 1987).

In Ethiopia, most of the ornamental crops and leguminous plants are growing under considerably warm and sunny climatic conditions. The greenhouse production system is a relatively new but increasing in the horticulture sub-sector in Ethiopia (Teshome and Dürr 2016). The most common greenhouse type is a basic steel construction with a fixed or adjustable single roof vent or side vents. The constructs are covered with plastic films (mainly polyethylene) to decrease the light intensity for creating a cooler environment. The use of different types of colored filters and cover materials to regulate desired physiological and morphological responses in plants is a new agro-technological concept, and is of increasing interest in Ethiopia. There are different cover materials used but most common types are locally produced cheap plastic films. Other, more expensive types of shading materials like colored nets (Shahak *et al*., 2004) or shading materials with reflectors and open strips to allow ventilation by free airflow through the opening (Hemming et al., 2005) – have, to our knowledge, not been tested and compared with the locally produced plastic films commonly used in Ethiopia.

In this study three different covering materials were compared, one cheap locally produced plastic film (yellow), imported plastic film (white) and imported shading material with strip ventilation (Svensson). The objective of this study was to assess growth and productivity of pea under the three different coverings and to evaluate their potential under Ethiopian growing conditions.

Materials and Methods

Experimental location and set-up

The field experiment was conducted in Hawassa, in the southern part of Ethiopia, during the dry season (January–April) 2016 and 2017 of each year. Hawassa is located at 7°3′N 38°28′E and at an altitude of 1700 meters above sea level (masl). The three types of covering materials used in the study were: (1) custom made Svensson shading screen (AB Ludving Svensson Bangatan 8,511 54 Kinna, Sweden), (2) white UV blocking plastic film (Solar EVA- 5 High diffuse opaque film with 0.20 mm thick, Rovero plastic (Krabbescheer-6 4941 VW Raamsdonksveer, The Netherlands) that selectively cut off solar spectrum below 350 nm , and (3) yellow plastic film (0.2 mm polyethylene sheet produced by the Ethioplastic company, Addis Ababa, Ethiopia). Plants grown under Svensson screening material will,

hereafter, be referred to as "Svensson'', those grown under white UV screening plastic film as "white", and those grown under yellow plastic film as "yellow''.

The shade structures were constructed from wooden frames having an area of 4 m^2 and a height of 2 m. In each structure, about 15 cm of open space was left uncovered below the roof and above the ground for air circulation. The structure was erected in the north–south direction over the treatment plot. This orientation ensured that solar radiation reached the plant only after passing through the filter as the sun moved from east to west.

The light spectrum transmittance of the two plastic films (Fig 1A), imported plastic film (White) and local plastic film (Yellow) were measured at Norwegian University of Life Sciences (NMBU) by illuminating the sample at the port of an integrating sphere (ISP-50-REFL Ocean Optics, Ocean Optics, Dunedin, Fla., USA) with 600 µm thick optical fiber and a DH2000 (Ocean Optics) halogen light source. The light transmitted into the sphere was measured with 400 µm fiber connected to an Ocean Optics SD2000 spectrometer. The direct light (Fig1B) was measured by the company Svensson with a spectroradiometer (LI-1800, L-Cor, USA). A SUN 1200 (Honle Germany) was used as a light source. Small samples of the coverings were placed over an integrated sphere connected to the spectroradiometer. The visible light range (400–700nm) was used to determine percent direct light under Svensson screening materials (Fig 1B).

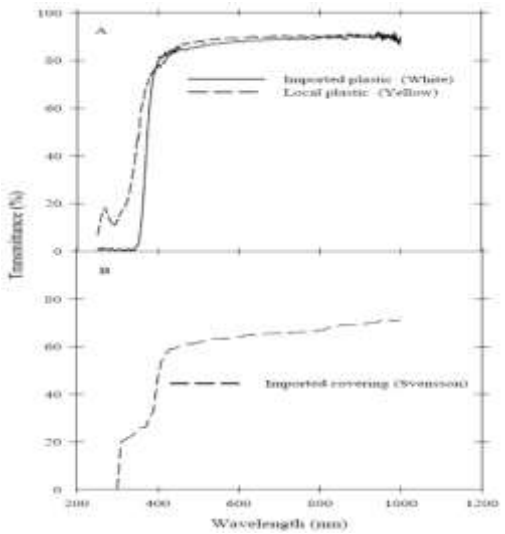

Fig. 1. Light transmittance through (A) imported plastic film Solar EVA- 5 High diffuse opaque film 0.20 mm thick (White) and locally produced 0.20 mm polyethylene sheet produced by Ethioplastic Company, Addis Ababa (Yellow) and (B) imported custom made shading screen (Svensson).

Climatic data and measurement

Climatic parameters such as temperature and relative air humidity (RH) were sampled every hour in a 24 hour cycle on 12 selected days during the experimental period (77 days), by the use of mini data loggers (Testo 174H, Version 5.0.2564.18771, Lenzkirch, Germany). Each data logger was hung close to the plant canopy (1 m above the ground).The UV-B (W m^{-2}), PAR (µmol m^{-2} s^{-1}), and Red to FarRed (R:FR)ratio were

measured two times every hour from 06:00–18:00h, on four days, using Skye spectrosense2 (Skye Instruments Ltd, UK).

Pre-cultivation and experimental growth conditions

Seeds of pea (*Pisum sativum cv.* Oregon sugar pod II) were obtained from a commercial farm (Hadia flowers and vegetables farm, Addis Ababa, Ethiopia) and sown directly in pots (15 cm size) filled with coconut peat (Galuku Lanka Exports Pvt. Ltd., Sri Lanka) and fertilized with 28 ppm diammonium phosphate (DAP; $(NH_4)_2HPO_4$, 18%N, 46%P_2O_5), following the methodology of Valenzuela (1983). The pots were placed in a shade house prepared for seed germination using CRD design and replicated three times. They were arranged in the shade house (25% shade) and subjected to similar environmental conditions – at a temperature of 20 °C and 70% RH, with 12/12 hour light/dark during germination of the seeds. The photoperiod was 12 hrs. Six days after germination, when the shoots were 1–2 cm in length, 30 pots were transferred to each experimental plot covered with the different screens.

Plant material and growth analysis

Growth measurement of young plants

Non-destructive growth data such as leaf thickness, stomatal conductance, leaf surface temperature and chlorophyll fluorescence measurement were collected from 4–5 weeks old vegetative plants. Another group of plants (six plants per treatment) were used for destructive measurements like collection of imprints of leaf epidermis, leaf dry weight, stem dry weight, leaf weight ratio (LWR= total leaf dry weight/ dry weight of vegetative part), and specific leaf area (SLA=leaf area of single leaf/dry weight of single leaf) at the stage of 4–5 weeks age. For determination of SLA, single leaf area and dry weight, leaves were collected from the 4^{th} node of six plants in each treatment. Leaf area ratio (LAR= leaf area per plant/weight per plant) and LWR were calculated based on the leaf area, and the above ground fresh weight and dry weight of each plant. Leaf thickness was measured with a digital vernier caliper on leaves from the 5^{th} node.

Stomata parameters

Stomata number and morphology was measured on three fully expanded leaves harvested from 4^{th}, 5^{th} and 6^{th} nodes of five plants during morning (10:00 to 11:00 hrs) time. To evaluate stomata morphology and features,

epidermal imprints were made on the upper surface of fully expanded leaves by coating approximately a 1.5 cm x 1.5 cm area of the leaf surface with clear nail polish. After 10 minutes the painted area was covered with transparent 'sellotape'. The imprinted epidermis was immediately fixed to a glass microscope slide and samples were kept at the Horticulture laboratory (Awassa College of Agriculture, Ethiopia) until it was transported to Norway. At Norwegian University of Life Sciences (NMBU) the negative imprints were photographed using Leica DM5000 B microscope (Leica Microsystems, Buffalo Grove, Illinois, USA) at 40x magnification, Leica DFC425 digital camera (magnification 0.5x), and Leica application LAS V370. Stomata length was quantified by measuring longitudinally from end to end, stomata aperture was quantified by measuring the opening distance between the two guard cells, and the stomata area was determined by measuring the circumference of the stomata.

Chlorophyll fluorescence

Chlorophyll fluorescence was measured on fully expanded leaves (at the 4^{th}, 5^{th} and 6^{th} nodes) from three plants in each treatment, during morning time (06:00–07:00 h), using a plant efficiency analyzer, Handy-*PEA* (Hansatech, Kings Lynn, UK), following the methodology of Strasser et al. (2004). Measurements were taken from 4-week old plants. For maximal chlorophyll fluorescence emission, leaves were dark-adapted in the leaf clip for 15 min. Light was then provided by an array of three high-intensity light-emitting diodes at 1500 µmol m^{-2} s^{-1} to ensure that the photosynthesis was fully saturated during the measurements.

Stomata conductance and transpiration rate

Stomatal conductance (gs), leaf surface temperature and transpiration rate (mmol m^{-2} s^{-1}) were measured on fully expanded leaves of three plants (4-week old plants) at the 5^{th} node, using an open system LCA-4 ADC portable infrared gas analyzer with leaf chamber PLC-4 (Analytical Development Company, Hoddeson, England). The transpiration rate was measured from the water vapor pressure of the air entering and leaving the leaf chamber. This measurement was taken from 12:00 to 13:00 h (local time) after 5 minutes, with the following specifications/adjustments: leaf surface area 6.25 cm^2, ambient carbon dioxide concentration 340 µmol mol^{-1}, temperature in leaf chamber varied from 34 to 47 ^oC, leaf chamber molar gas flow rate 410 $\mu mols^{-1}$, ambient pressure 828 mbar and PAR at leaf surface was maximum 1500 µmol m^{-2}. Three plants were selected from each treatment. In each plant a fully opened leaf (5^{th} node) was used for stomata conductance, leaf surface temperature and transpiration rate measurement. Measurements were

taken in each leaf every 5 minutes for 15 minutes.

Measurement of growth and flowering of pea

During 5 weeks of growth stage, parameters like plant height, leaf number, internode number and internode length were measured every 7^{th} day. Plant height was measured with a ruler from the top surface of the pot to the shoot apical meristem until the first flower bud appeared. After flower initiation there was no further shoot elongation of the main stem. Leaf number was determined by counting fully opened leaves on each node of the main shoot. All internodes below the newly opened leaves were counted and measured to determine the number of internodes. Internode lengths of six plants from each treatment were determined by measuring the length between the nodes. The appearance of flowers was recorded every third day, starting from week five – when the first flower appeared – until the appearance of new flowers stopped (8^{th} week).

Measurements of pod size and above ground biomass

Pod length and width were measured during pod development, beginning 4–6 days after flowering when the pods were < 0.5 cm. The length and width were measured every day until pod extension stopped (seed filling stage) (Ohyama, 1983). Pod length (longitudinal section) and width (horizontal section) were analyzed at seed filling stage (about 15–20 days after flowering). The lengths of the pods were measured longitudinally, following the curvature of the pod. Pod width was measured at the middle of the pod length. During harvesting the total number of pods per plant, as well as the total and the individual pod fresh weights were determined. Leaves and stem of each harvested plant were separated, and fresh weights of stem and leaves were measured. Leaf area per plant was measured with an LI-3100 leaf area meter (LI-COR, Inc., Lincoln, Nebraska, USA). Dry weight of above-ground biomass was measured after drying at 70 ^{o}C for 72 hours.

Statistical analysis

Significant differences between means were tested using one-way analysis of variance (ANOVA) and Tukey's test with $P \leq 0.05$ significance level. Average values for each plant were used in the analysis. Data were checked for equal variance before ANOVA analysis. All statistical tests were performed in Minitab 16.1.1 (Minitab 16.1.1, Windows version, State College, Pennsylvania, USA).

Results and Discussion

Climate data and measurement

The purpose of this study was to compare three different covering

materials and evaluate their effects on growth and development of pea under Ethiopian climate. The light conditions and temperature measured under each screen material are presented in Table 1, and Fig 3. Although a big difference in mean temperature was not observed, the temperature under the yellow plastic cover seems higher by 1– 2 ℃ during the middle of the day (12:00–14:00 local time) as compared to the Svensson and the white covering materials (Fig. 3). Since Svensson covering is a ventilated reflective screen with lower light transmission, a lower leaf temperature was expected as compared to the two plastic films. However, no significant differences in leaf temperatures inside the small (4 m^2) greenhouses were found (Table 1).

Table 1: Ambient irradiance levels and irradiance levels of UV-B (W m^{-2}) and photosynthetic active radiation (PAR) (µmol m^{-2} s^{-1}) and R:FR ratio below Svensson, white and yellow screens were measured in the middle of the day (11:30-14:30) at Hawassa, south Ethiopia, during the dry (January–April) season of the year 2016 and 2017 each year.

Screens	UV-B Ambient (W m^{-2} s^{-1})	UV-B below screen (W m^{-2} s^{-1})	% UV-B reduction	PAR Ambient (µmol m^{-2} s^{-1})	PAR below screen (µmol m^{-2} s^{-1})	% PAR reduction	R:FR ratio
Svensson	1.8	0.3	85	2000	612	70	0.95±0.01c*
White	1.8	0.08	96	2000	1083	46	1.0±0.01b
Yellow	1.8	0.43	77	2000	1372	31	1.11±0.00a

* Different letters in the R:RF ratio column indicate statistically significant difference at p≤0.05, Tukey's test. Percent reduction in irradiance below the screen, compared with ambient irradiance levels also shown. R:FR ratios were measured two times every hour from 11:30–14:30 on four days. Data in the R:FR is the mean value ± SE, (n=4).

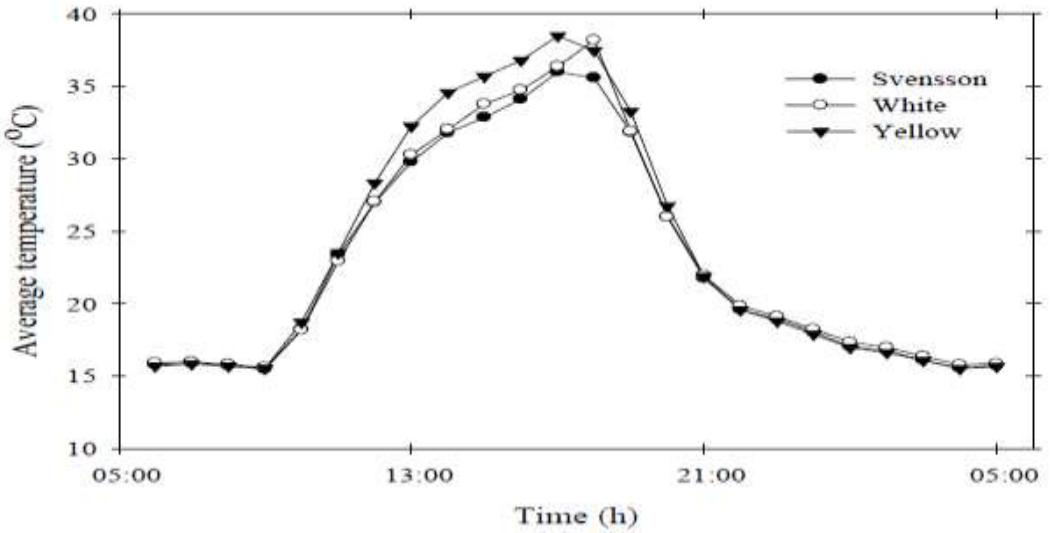

Fig. 3: Average temperatures measured across the different greenhouse screens during the dry seasons of 2016/17 at Hawassa, south Ethiopia. The temperature was sampled using a mini data logger, hung on the top of the plant canopy inside each covering material, during the experimental period (77 days). Data were measured every hour in each treatment for 12 days. Each point represents the average value of 12 measurements.

The main difference between the Svensson covering and the plastic films was lower PAR transmittance in the case of the former (Table 1). Svensson covering material had 55% and 43% less PAR than the locally produced yellow plastic shading material and the imported white plastic cover material, respectively (Table 1). However, the latter two had almost the same PAR levels. Moreover, the ratio of red to far red light (660/730 nm) was slightly higher under locally produced plastic cover material than under the two imported covering materials. The lowest R/FR ratio was measured under the Svensson covering material (Table 1). This was due to plant morphology and productivity are commonly influenced by environmental factors such as light, temperature and air humidity (Eskins, 1992; Jansen et al., 1998; Mortensen, 2000) as it has more ventilation. However, the differences in productivity were found to be rather small in this study. The UV-B level was only 4% under the white plastic covering material, as compared to 17% and 23 %, respectively, under the Svensson and the local covering material. (Table 1). The plants were more elongated under the Svensson screen. It is likely that the reduced irradiance and the lower R:FR ratio in the Svensson covering material are the reasons for the growth stimulation, as compared to the plastic film (Table 1 and Fig 1). Moreover, in addition to longer internodes, the plants grown under the Svensson screen had significantly more internodes – indicating that the growth rate (leaf/day) must have been higher in

plants developed under the Svensson screen, as compared to the two plastic films. Pea is a fast growing type of vine crop that requires support to hold the plants uprights as they grow taller. In a commercial production system, dwarf varieties that only grow 30-60 cm in height might be optimal without additional support from staking or trellis material. Dwarf plants are also strong enough to self-support and keep their pods away from the soil surface (Powell & Marks, 2003; Tsado, 2012). Nevertheless the results showed that all covering materials resulted in rather short plants (< 40 cm).

The transmission in the field is much more reduced than in the laboratory for the Svensson screen (Fig. 1B). , whereas . This difference could be explained by the reduction in the dust transmission and by the "tent" effect. The "tent" effect means that much of the light transmitted through the Svensson screen is diffused light. This diffused light will be spread in all directions over a much larger area than the roof area. Therefore, the light reaching the plants will be much attenuated. This "tent" effect will be much greater in these small experimental tents than in tents with a large roof area. For the two other clear screening materials more of the light transmitted is direct light and less diffused light. The tent effect will be smaller and the difference between lab measurements and field measurements of light transmission will be less (Fig. 1).

Morphology of young plants

Leaf traits, stomata aperture and stomata area

Leaf area ratio (LAR) was 14% and 16% higher for leaves developed under the Svensson screen, as compared to the white and the yellow covering materials, respectively (Table 2). However, leaf thickness, specific leaf area (SLA) and leaf weight ratio (LWR) were not significantly different between the coverings (Table 2). Smaller stomata aperture was found for plants produced under the yellow film, as compared to the white plastic and the Svensson screen. A similar trend was found in stomata area (Table 3). However, no significant difference in stomata number was found between the treatments. Plants under the Svensson covering material had 16% higher LAR than plants grown under the yellow plastic material. Poorter and Remkes (1990) reported that fast growing plants have a higher LAR, which is the fraction of total plant weight allocated to leaf area, than slow growing plants. Moreover, others have indicated that shaded plants have a higher biomass allocation to leaves, and a higher leaf area per unit leaf mass, resulting in a higher leaf area ratio (Popma and Bongers, 1988; Osunkoya *et al.*, 1994). Our result confirmed that, plants grown under a lower irradiance, like those under the Svensson covering had higher LAR than plants growing under higher irradiance (Tables 1 and 2).

As in the case of stomata aperture, stomatal conductance and transpiration rate were significantly reduced under the yellow covering material, as compared to the white covering material and the Svensson screen (Table 4). Leaf surface temperature was not significantly different (Table 4). The yellow covering material induced a significant reduction in stomatal aperture and stomatal conductance. However, there was no significant difference between the Svensson screen and the white plastic film (Tables 3 and 4). The reduction in stomatal aperture and conductance resulted in reduced transpiration under the yellow covering material, probably because of the higher PAR and slightly higher UV-B. Previous studies also reported that exposure to UV-B radiation significantly reduces stomata density and opening in UV-B sensitive cultivars (Dai *et al.*, 1992; Jansen and Van Den Noort, 2000). We did not find differences in stomata number between the different coverings. However, we observed that higher UV-B and PAR under the yellow covering material reduced the stomata conductance by 34% and transpiration rate by 17% as compared to plants grown under the Svensson screen. Tossi et al. (2014) reported that higher UV-B influence strongly reduced stomata aperture and conductance in *Arabidopsis* plant.

Table 2: The impact of different covering materials on pea leaf parameters grown at Hawassa during the dry season (January–April) of 2016/17 year for 4–5 weeks old plants.

Leaf parameters	**Covering materials**		
	Svensson	White	Yellow
Leaf thickness (mm)	0.60±0.06a*	0.62±0.12a	0.67±0.15a
SLA ($cm^2 g^{-1}$ DW)	366.42±16.8a	375.40±61.1a	303.9±31.4a
LAR ($cm^2 g^{-1}$)	30.25±1.26a	25.92±0.70b	25.35±0.67b
LWR (g DW g DW^{-1})	0.54±0.02a	0.51±0.01a	0.53±0.01a

* Different letters in the same row indicate statistically significant difference at p≤0.05, Tukey's test. Values are mean values ±SE, (n= 6).

Table 3: The stomata number and stomata size in pea leaves grown under the three covering material at Hawassa during the dry season (January–April) of 2016 and 2017 each year).

Stomata parameters	**Covering materials**		
	Svensson	White	Yellow
Stomata number	12.0±1.26a*	14.0±1.0a	13.0±1.41a
Stomata length (µm)	19.52±0.90a	19.66±1.25a	17.65±1.19a
Stomata aperture (µm)	6.53±0.94a	6.13±0.73a	3.4±0.34b
Stomata area (µm^2)	199.92±8.85a	192.74±15.32ab	144.53±16.3b

* Different letters in the same row indicate statistically significant difference at P≤0.05, Tukey's test. The values are mean values ± SE, n=50. Five leaf samples were used to estimate stomata number and morphology. From each leaf sample, ten stomata were used to calculate stomata length, stomata aperture and stomata area.

Table 4 shows the impact of different types of covering material (imported Svensson and white plastic, and locally produced yellow plastic) on stomata conductance and transpiration rate.

Parameters	**Covering materials**		
	Svensson	White	Yellow
Stomata conductance (mmol m^{-2} s^{-1})	0.067±0.03a*	0.077±0.016a	0.044±0.003a
Transpiration rate (mmol m^{-2} s^{-1})	3.34±0.27b	4.4±0.28a	2.77±0.09b
Leaf surface temperature (℃)	34.18±0.58a	34.48±0.36a	35.18±0.12a
Fv/Fm	0.83±0.009a	0.79±0.005b	0.77±0.009c

* Different letters in the same row indicate statistically significant difference at P≤0.05, Tukey's test. The values show mean ± SE. Stomata conductance, transpiration rate and leaf temperature were measured five times for each of three fully expanded leaves (average used in statistical analysis) from each of three plants (n=3). Three samples for chlorophyll were analyzed for one combined sample from each treatment (n=1). Measurements of Fv/Fm were taken from three fully expanded leaves from each of three plants (n=9). The values show mean ± SE.

Pea plants have rather shallow rooting depth (rarely exceeding 100–120 cm) as compared to barley (*Horeum vulgare* L.), wheat (*Tritium aestivum*) and lupin (*Lupines angusifolious* L.) in a similar soil type (Hamblin and Hamblin, 1985; Hamblin and Tennant, 1987; Andersen and Aremu, 1991; Hauggaard-Nielsen *et al.*, 2001). These reports suggested that shallow root distribution might lead to late season water deficits. Agronomic techniques could be used to manipulate the morphology and physiology of plants to reduce water usage, thereby help shallow rooted crops like pea to grow and produce optimum yield under water stress conditions. Reduction in plant size and leaf area, promoting early flowering

and minimizing stomata conductance, are opportunities to manipulate water use efficiency against plant productivity (Blum, 2005).

Several studies clearly show that plants vary greatly in their response to ambient UV-B radiation. In some species enhanced UV-B radiation inhibited growth but in others it stimulated growth (Adamse *et al*., 1997; Krizek *et al*., 1997; Pal *et al*., 1997). Different reports also show that plants grown under high UV-B radiation suffer chlorophyll damage, which could be due to its direct absorption of UV-B (Lingakumar and Kulandaivelu, 1993) or due to inhibition in the Chl biosynthesis (El-Mansy and Salisbury, 1971). However, this was not the case in our experiments. The type of screen did not significantly affect the chlorophyll content in pea (data not presented). Removal of UV-B from the growth environment has been a common strategy to avoid UV related stress in plants. In our experiment the lowest Fv/Fm value was recorded on pea plants grown under the locally produced yellow covering material. Plants grown under the yellow plastic also received the highest level of PAR and UV radiation, compared to the other two imported covering materials. In many respects, plants grow as well under the Svensson screen as under the two other screens, although the light level is about half under the former as compared to the latter (Table 1).These results indicate that photosynthesis is already saturated at about 600 µmol $m^{-2} s^{-1}$.

Therefore, a doubling of the light level will not resulted in increased growth. This explanation is supported by the dawn measurements of Fv/Fm. Maximal PSII efficiency values of 0.77 and 0.79 in the morning, compared with 0.83 for plants under the Svensson screen, indicate that the plants under the two plastic films have not recovered fully from photoinhibition caused by excess light the previous day (Table 4). The high Fv/Fm value (0.83) for plants grown under the Svensson screen indicates that these plants are not stressed by high irradiance. Values close to 0.83 indicate unstressed plants (Baker, 2008).

Overall, however, only small differences were found between the more expensive imported white film and the less expensive locally produced covering; no differences were found in yield and pod quality. The locally produced yellow plastic cover might, therefore, be recommended for pea production in Ethiopian climate. However, the stability of the plastic covers was not tested in this study. Some films degrade easily in high light intensities and this is also an important quality parameter to evaluate.

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Chlorophyll fluorescence

Plants grown under the Svensson screen had higher maximal photosystem II efficiency (Fv/Fm) than plants grown under the white and the yellow covering materials (Table 4). The lowest Fv/Fm value was measured in plants grown under the local yellow plastic

Measurement of morphology and grain yield

Plants grown under the Svensson covering material were 5.1 and 6.4 cm taller than plants grown under the white and the yellow coverings, respectively (Fig. 2). Plants produced under the Svensson covering material had 2–3 more internodes and 0.44 to 0.59 cm longer individual internodes than plants produced under the white and the yellow covering materials (Table 5).

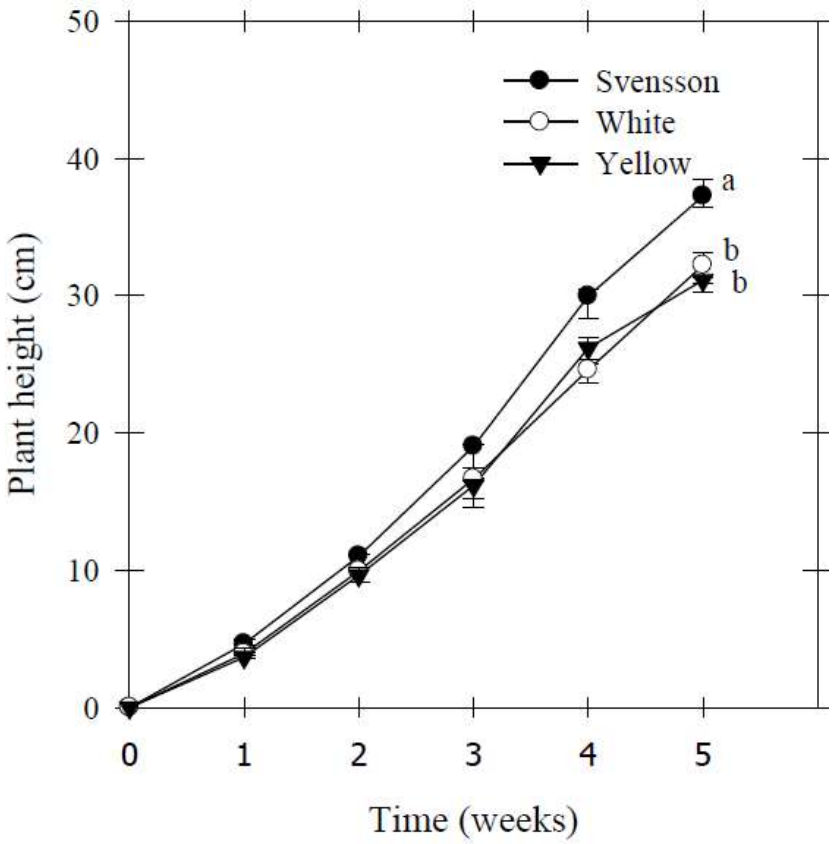

Fig. 2. Plant height was measured for pea plants grown under imported covering material (Svensson and white) and locally produced covering material (yellow) at Hawassa (1700 masl) in Ethiopia during the dry (January–April 2016/17) season. Values are the mean of six plants ±SE.

Table 5: The effects of different covering materials on the growth and morphology of plants grown during the dry season (January–April) of 2016 and 2017 each year at Hawassa

Growth parameters	Covering materials		
	Svensson	White	Yellow
Leaf number	23.7±2.69a*	20.7±2.20a	26.0±2.80a
Leaf area (cm²)	555.3±93.9a	461.4±41.6a	545.7±34.4a
Internode number	16.17±0.60a	15.33±0.67ab	13.00±0.68b
Internode length (cm)	3.4±0.14a	2.96±0.12ab	2.81±0.2b
Flower number	12.3±0.97a	11.00±1.19a	13.8±0.51a

* Different letters in the same row indicate statistically significant difference at p≤0.05, Tukey's test. Leaf number, internode number and internode length were recorded from six plants every seven days. However, total leaf area was measured at week five, when the plants showed the first flower bud. The data are the mean values of measurements from six plants in one counting (Mean ± SE, n= 6).

No differences were observed in flowering time between plants grown under the different covering materials. All the plants flowered after five weeks (data not shown). Moreover, all covering materials had similar effects on leaf area, leaf number and flower number during the growing period (Table 5). The number of pods, pod length, pod width, number of seeds per pod, as well as pod fresh weight per plant and individual pod fresh weight, were similar and no significant differences were found among the covering materials (Table 6). Furthermore, no significant differences in dry matter accumulation and distribution were found between the treatments (Table 7). This shows that the pea plant is robust to changes in light climate.

Table 6: The productivity of pea plants grown under different covering materials at Hawassa, south Ethiopia, during the dry season (January–April) in 2016/17.

Yield parameters	Covering materials		
	Svensson	White	Yellow
Number of pods plant^{-1}	6.67±0.92a*	6.67±1.36a	7.33±1.41a
Pod length (cm)	6.71±0.20a	5.87±0.18a	6.47±0.30a
Number of seeds pod^{-1}	4.4±0.19a	4.2±0.15a	4.5±0.25a
Pod width (cm)	1.92±0.08a	1.84±0.10a	1.90±0.10a
Fresh weight of pods plant^{-1}	14.89±1.66a	13.88±4.47a	15.76±2.32a
Fresh wt. per pod (g)	2.42±0.41a	1.89±0.322a	2.3±0.233a

* Different letters in the same row indicate statistically significant difference at P≤0.05, Tukey's test. The values are the mean ±SE of six plants.

Table 7: The dry matter distribution of pea plants grown under the three covering material at Hawassa during the dry season (January–April) in 2016/17.

Parameters	Covering materials		
	Svensson	White	Yellow
Total dry weight (g)	7.14±0.42a*	7.79±0.38a	8.00±0.44a
Leaf dry weight (g)	1.16±0.26a (16.25%)	1.11±0.11a (14.25%)	1.29±0.06 (16.13%)
Stem dry weight (g)	0.95±0.16a (13.3%)	1.07±0.13a (13.74%)	1.17±0.1a (14.63%)
Pod cover dry weight (g)	0.63±0.05a (8.82%)	0.65±0.23a (8.34%)	0.74±0.12a (9.25%)
Seed dry weight (g)	4.41±0.28a (61.76%)	4.95±0.33a (63.54%)	4.79±0.38a (59.88%)

* Different letters in the same row indicate statistically significant difference at p≤0.05, Tukey's test.The data shown are the mean values of measurements from six plants in one counting (Mean ± SE; n= 6). Values in parentheses indicate the proportion of dry matter allocated to different plant parts.

Conclusion

The present study shows that the pea cultivar used in this study is robust to changes in light climate. Pea grown under the cheap locally produced yellow plastic screen produced similar number of pods to that grown under the more expensive imported screening material tested in this study. The higher transmission of PAR and UV-B through the yellow plastic film significantly reduced plant height, internode number, internode length and Fv/Fm, as compared to the imported Svensson screen, but the changes did not affect the yield. Lower stomata aperture and leaf conductance were measured under the yellow screen and resulted in reduced transpiration rate, as compared to the imported screens. Thus, the yellow screens can be efficient in reducing the water consumption in pea production. However, cost benefit analysis and the quality of the plastic (e.g. its stability) needs to be studied further.

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