Using Agrovoltaics to Shade Bok Choy Variety Trial

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Abstract

Bok choy (*Brassica rapa* subsp. *chinensis*), also known as pac choi, is an Asian, cool season, brassica crop that should theoretically grow well in the mild, temperate climate of Southwestern British Columbia. However, one challenge is that the crop easily bolts (initiates flowers) during high temperatures in the summer. Bolting results in an unmarketable crop due to physiological changes that leave the vegetable bitter in taste. As climate change becomes of increasing concern, there is increasing importance into conducting research on better varieties that are able to manage increasing temperatures. However, with an aim of greater agroecosystem resilience, a diversity of mitigations should also be considered, such as microclimatic controls in reducing bolting and yield losses. Shading with shade cloth is one way to help cool a field of crops, but Agro-Photovoltaic (APV) systems that pair solar panels with crops that benefit from partial shade leads to a dual-purpose of land use, producing both renewable energy and food. This study aimed to compare five Bok choy varieties on their bolt resistance and yield across two different plantings in 2023, one in June and another in August, as well as the effect of different shading methods. This study found that there was a significant effect of variety, but not of planting date or of shade method, on the marketable yield (lb.) of Bok choy. This study also found that the electrical output of a solar panel (CAD$0.66) compensated for the yield loss of Bok choy shaded under the panel (CAD$0.45), indicating feasible compatibility of an APV system with Bok choy for Richmond, BC.

Keywords: variety trial, Bok choy, Pac choi, *Brassica rapa* subsp. *chinensis*, shading, solar panel, shade cloth, agro-photovoltaic, APV, agrivoltaics, agrovoltaics, bolting, bolt resistance, yield, electricity production

Introduction

Bok choy (*Brassica rapa* subsp. *chinensis*), also known as Pac choi, is an Asian brassica crop. It is a cool season crop with an optimum growing temperature of 18-20°C, but can even grow successfully in hot, dry climates like Texas, USA (Niu et al. 2021). One challenge with growing Bok choy in the height of summer is that high temperatures can induce bolting (flower initiation). This causes physiological changes resulting in the vegetable becoming bitter in taste (Nair et al. 2015). Even in the mild temperate climate of Southwestern British Columbia, it has been observed that bolting of Bok choy in the summer months occurs at the KPU Garden City Farm in Richmond, BC (Smith 2023). Kalisz et al. (2012) observed that there is an interaction between Bok choy cultivar and the growing period on yield, which aligns with the assertion by Siomos (1999) that genotype and temperature are the major factors that affect bolting. For the bioregion of Southwestern BC, this study aimed to compare five Bok choy varieties on their bolt resistance and marketable yield across two different plantings – June and August – which was expected to differ in ambient temperature.

Additionally, shading is expected to contribute to bolt resistance and the yield in Bok choy. Shading would contribute to lowering microclimatic ambient temperature but would also lower light irradiance which could negatively affect crop yields. However, with crops that bolt easily due to high temperatures, there is potential of using a solar photovoltaic system to maximize crop yield while using the shading implement to capture solar energy. With climate change becoming an increasing concern, there has been an emphasis of moving away from fossil fuels towards renewable energy sources – one method being solar farms consisting of hundreds to thousands of solar panels. Thus, solar farms do exist for this purpose, but a disadvantage is that they take up a lot of land which could instead be used for agriculture or for environmental conservation. For example, according to the 2021 development plans for 15 solar farms in Indiana, USA, each was planned for more than 1000 acres, with the largest being 4500 acres in size ("SOLAR MEADOWS" 2021).

The combination of agriculture and solar photovoltaics, first conceptualized by Goetzberger and Zastrow (1981) as an agro-photovoltaic (APV) system, would maximize land-use through its dual purpose in bolstering both the agriculture and energy sectors. Besides converting solar farms into APV systems, existing farmlands can also be converted into APV systems. In fact, it is estimated that converting just 4% of Canada's existing agricultural land could supply the country's energy needs ("Experts root for agrivoltaics to solve clean energy, agricultural needs." 2022). Over the course of 40 years, APV systems for both animals (Blumberg 2021) and crops (Lee et al. 2022; Cossu et al. 2014; Marrou et al. 2013) have been studied and, in some cases, implemented. In their meta-analysis on APV cropping systems, Laub et al. (2022) found that berries, fruits, and fruity vegetables benefited from shading according to their yield compared to the unshaded control. For leafy vegetables, in which Bok choy would be considered, the yield of the shaded groups was generally lower than that of the unshaded control (Laub et al. 2022). Nevertheless, Laub et al. (2022) call for more research on determining suitability of various crops into APV systems, with one suggestion being that future studies should test different shading methods in the same location. Thus, for the bioregion of Southwestern BC, this study also aimed to compare shading methods ('solar panel,' shade cloth, and unshaded control) on Bok choy bolt resistance and yield, to determine if an APV system with Bok choy is a compatible pairing.

This study had five main objectives. The first objective was to determine if the yield and bolt resistance differs between five varieties of Bok choy: Bopak, Chun Mei, Joi Choi, Mei Qing

Choi, and Summer Zest. Mei Qing Choi was the check variety in this study because it is commonly grown and is marketed as being slow to bolt. It is the variety that the other varieties will be compared to.

Null Hypothesis (H_0): Bopak, Chun Mei, Joi Choi, and Summer Zest do not have a different yield and bolt resistance than the check variety, Mei Qing Choi

Alternate Hypothesis (H_A): Bopak, Chun Mei, Joi Choi, and Summer Zest do have a different yield and bolt resistance than the check variety, Mei Qing Choi

The second objective was to determine if shading has an effect on the bolting of Bok choy. The control group was unshaded, and the two experimental groups were 50% green shade cloth and a pseudo-solar panel ('solar panel'), a sheet of plywood with a light sensor attached.

H_0: Shading via 'solar panel' and shade cloth does not have an effect on yield and bolting of Bok choy

H_A: Shading via 'solar panel' and shade cloth does have an effect on yield and bolting of Bok choy

The third objective was to determine if planting date has an effect on yield and bolting resistance. There were two plantings: a June harvest and an August harvest.

H_0: Planting date does not have an effect on yield and bolting of Bok choy

H_A: Planting date does have an effect on yield and bolting of Bok choy

To summarize the first three objectives, there were three factors being studied – the Bok choy variety, the shading method, and the planting date – at five, three, and three levels, respectively.

The fourth objective was to determine if there were two-way interactions between the three factors: variety with shading method, variety with planting date, and shading method with planting date. Finally, the fifth objective was to compare the total output (Bok choy value and electrical value) from plots with and without the 'solar panels.' Calculating the theoretical production of electricity from the 'solar panels' was done to estimate the electrical yield and its subsequent value.

Methods

This study was conducted at the KPU Farm on the Garden City Lands in Richmond, BC from May 16, 2023 to August 20, 2023. It was conducted on the northern end of Market Garden E (49°10'28.2"N 123°07'20.4"W), with a total size of approximately 3 m x 30 m. In 2022, root vegetables like carrots, beets, and parsnips were grown in Market Garden E. Using a Randomized Complete Block Split-Plot Design (Figure 1), each block consisted of three plots randomized by shading method and was replicated three times. Each plot was 1 m x 1.7 m with a 1.6 m buffer in between each plot. Each plot was divided into 25 subplots, randomized through a Latin Square Design with 5 plants of each variety, with an in-row spacing of 30 cm and a between-row spacing of 15 cm. A sensor housing unit consisting of an ambient temperature sensor (Gikfun model DS18B20, Amazon.ca), a light sensor (Adafruit model 4162, Mouser Electronics, Canada), and a soil moisture sensor (DFRobot model SEN0193) was placed near the center of each plot (Figure 2). Microcontrollers/development boards (Espressif model ESP32-DevKitC-32E, Mouser Electronics, Canada) logged the sensor data. Rechargeable LiPo batteries (Starlight Power Technology model RB-Sta-24, RobotShop, Canada) powered the sensor unit and were recharged with battery chargers (DFRobot model RB-Dfr-213, RobotShop, Canada). See Figures S1, S2, and S3 of Supplementary Figures for additional details of the sensor set-up.

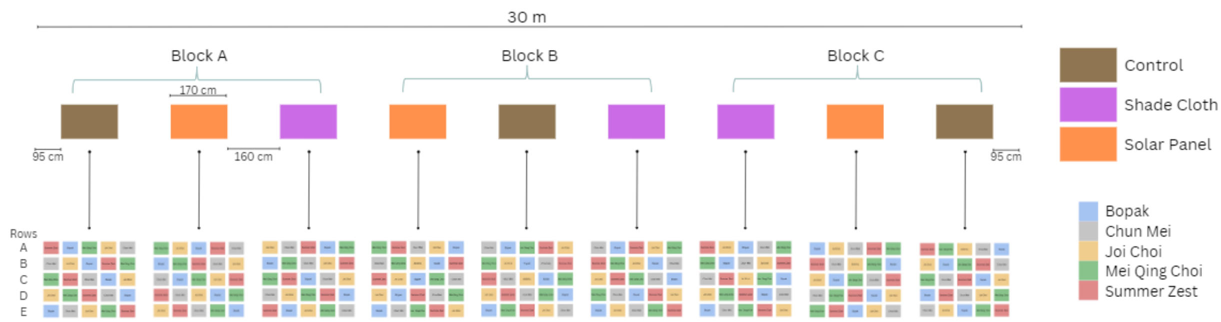

Figure 1. Block Layout via Randomized Complete Block Split-Plot Design & Sub-plot Layout via Latin Square Design

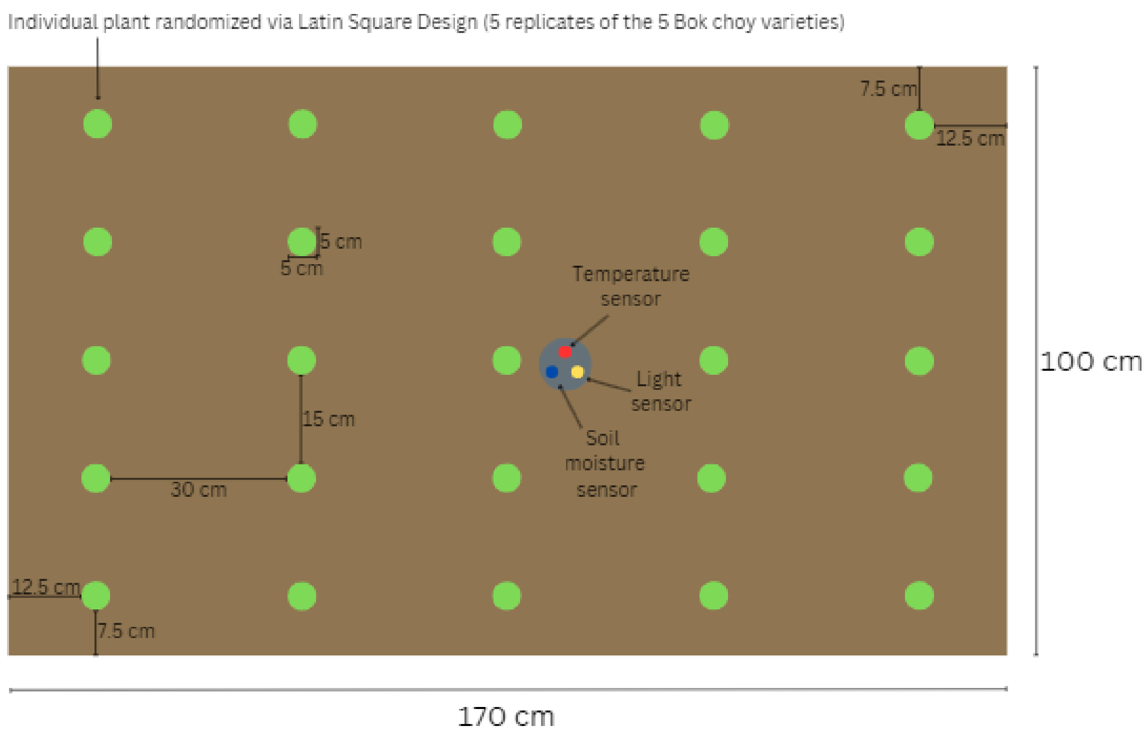

Figure 2. Layout of each plot.

For the plots with 'solar panels,' the goal was to have the shade cover the entire plot when the sun was at its peak at 12 pm by aligning the center of the 'panel' with the center of the plot. They were placed in preparation for the June planting, and remained in place for the August planting. This study did not use actual solar panels. Model 'solar panels' were made of ⅜" plywood, with the same dimensions as the plot at 1 m x 1.7 m, were painted black, and had an additional light sensor placed at the center of the plywood (Figure S2). According to Boxwell

(2019), the optimum tilt of a solar panel for Richmond, BC is 57° in May, 57° in June, and 41° in September from the vertical. These months were the original harvest dates for this study. Thus, the calculated mean optimal angle for these months is at approx. 54°. With the angle set at 54°, the northern edge of the solar panel was 24 cm in from the southern edge of the plot, while the southern edge of the solar panel was 57 cm out from the southern edge of the plot. The height of the southern edge of the solar panel was 71 cm from the surface of the soil (Figure 3).

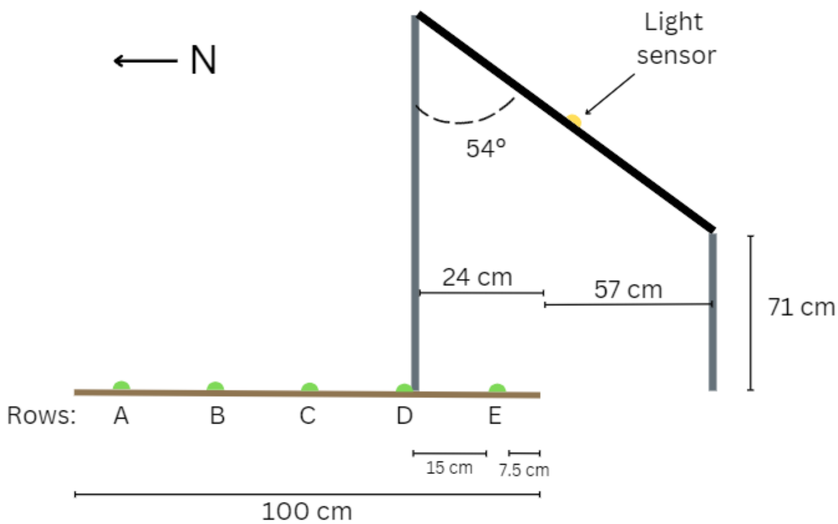

Figure 3. 'Solar Panel' set-up with 54° angle from the vertical

For plots with shade cloth, 3 hoops were placed into the soil, one on the west and one on the east sides of the plots, with an additional hoop placed in the center. A 2 m x 4 m green shade cloth with 50% light blocking ability (Lee Valley, Vancouver, BC) was placed over the hoops, pulled taut, and secured by sand bags (Figure 4).

The five Bok choy varieties were:

1. Bopak (Johnny's Selected Seeds, 50 days-to-maturity);
2. Chun Mei (Kitizawa Seed Co., 45-50 days-to-maturity);
3. Joi Choi (West Coast Seeds, 40-50 days-to-maturity);
4. Mei Qing Choi (West Coast Seeds, 40 days-to-maturity); and

5. Summer Zest (Kitizawa Seed Co., no listed days-to-maturity).

These varieties were selected based on growth habit (disregarded Tatsoi-like varieties) and size (disregarded baby varieties). The check variety, Mei Qing Choi, is considered medium in size growing to a mature height of between 8-10," while the other varieties in this study are considered medium to large. All are hybrid varieties, and only Bopak is an organic seed variety. Chun Mei, Mei Qing Choi, and Summer Zest are green stem varieties, while Bopak and Joi Choi are white stem varieties.

The 3 m x 30 m experimental site was fertilized on April 4, 2023 with 3.2 kg (7 lb.) of blood meal (13.6-0-0, APC Agro) and 3.2 kg (7 lb.) of feather meal (13-0-0, Gaia Green Organics). The area was covered with landscape fabric to kill cover crop and weeds until April 28, 2023 when the soil was rototilled with a BCS. The soil was not amended again between plantings, but was again covered to kill weeds before the transplanting for the August planting.

The Bok choy seedlings were started indoors in size 60 soil blocks (May 16, 2023 & July 11, 2023), then transplanted out into the plots on day 17 after sowing date to ensure the best start for the seedlings. The beds were flame-weeded immediately before transplanting. Once transplanted (June 2, 2023 & July 28, 2023), all plots were covered with polyester row covers (ProtekNet, 89% light transmission; 62% porosity) for 7 days to protect the seedlings from birds as they transitioned to their outdoor environment (Figure 4a). Weeding was done by hand hoe once a week. The grass at the perimeter of the plots was monitored and was mowed on July 28, 2023. The plots were irrigated by drip line instead of overhead sprinklers to avoid watering the 'solar panel,' as well as to reduce incidence of diseases that thrive in moist environments. Initially, each plot had two drip lines, one between rows A and B and another between C and D, but the crops in row E were not getting sufficient water so an additional line was added south of row E soon after the June planting. From then on, all plots had three drip lines that were scheduled to irrigate three times a week at 5:00 am PDT for 120 minutes.

Data collected continuously throughout the study included ambient temperature, light irradiance, and soil moisture via their respective sensors. The soil moisture sensor was calibrated by holding the probe in the air for the 0% saturation reading and then into water for the 100% saturation reading. See Supplementary Data for the programmed code for the sensors.

The data collected by the light sensors was used to estimate the light energy captured by the 'solar panel', which then was used to calculate the power generated (kWh). Two corrections first had to be performed on the 'lux' unit that the sensor collected. The clear, colourless acrylic plastic cover protecting the light sensor on the sensor units was found to block 90% of the incoming light, so the 'lux' unit first needed to be divided by 0.9 to obtain the true unblocked 'lux'. The unblocked 'lux' unit (x) was corrected to obtain the true lux using the formula:

$$y = 6.0135E\text{-}13x^4 - 9.3924E\text{-}09x^3 + 8.1488E\text{-}05x^2 + 1.0023E\text{+}00x \text{ (Schaar 2019)}$$

This was converted to watts (W), with an assumed efficiency of 20%, then to kilowatt-hours (kWh) by multiplying by time.

Data analysis for sensor data was done using the jamovi interface for R and using Microsoft Excel. For outliers in the lux and temperature data, jamovi was used to remove outliers within each hour increment (i.e. 5:00-5:59 am) by taking the square-root of the marketable yield (lb.), then visualizing it with boxplots that identified outliers. With the outliers removed, data visualization was done using Microsoft Excel.

During each planting, all plots were monitored for bolting and bolted plants were to be recorded in days to bolting from sowing date (Colorado State University n.d.). Based on the days-to-maturity of the varieties, the plants were harvested 40 d after sowing date (June 25, 2023

& August 20, 2023) (Figure 4b). Each plant was weighed and graded on a 5-point marketability scale (Appendix A). Weight (w) and marketability (m) were combined to calculate marketable yield (y*):

$$y^* = \frac{w(m-1)}{4}$$

Using this marketable yield scale, a group of plants averaging 5 on the marketability scale would have 100% marketable biomass, a group of plants averaging 3 would have 50% marketable biomass, and a group of plants averaging 0 would have no marketable biomass.

The data collected allowed analysis on the effect of Row on Marketable Yield, so Row was included as an independent variable. Data analysis for marketable yield was conducted using Mixed Model Analysis on the jamovi interface for R, where Marketable Yield was the dependent variable; Planting, Row, Shade Method, and Variety were the factors; Block, Column, and Plot were the cluster variables. Planting, Row, Shade Method, and Variety and their two-way interactions were the fixed effects while the Block-Intercept, Column-Intercept, and Plot-Intercept were the random effects. Bonferroni was conducted as the post-hoc test to determine statistically significant differences between means.

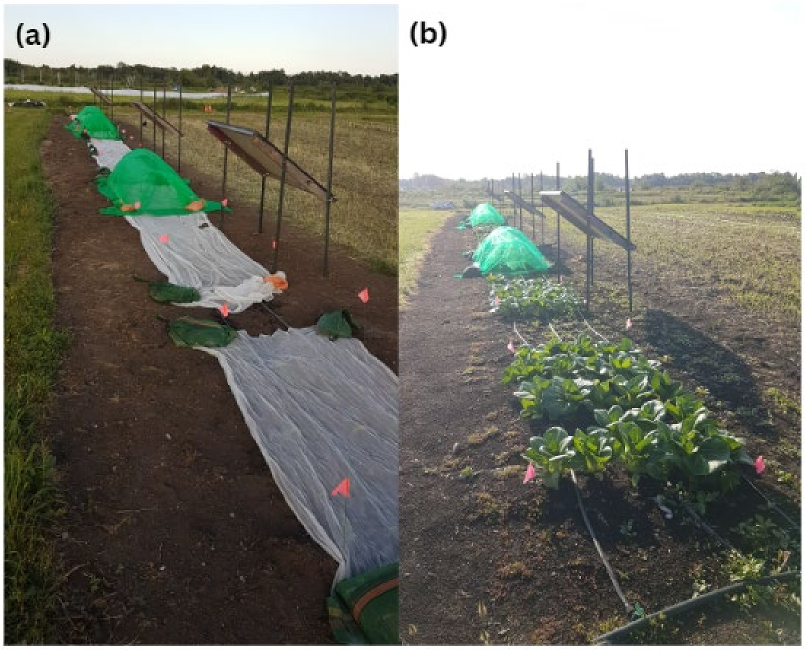

Figure 4. (a) Transplant day, where all plots covered with ProtekNet for 7 days **(b)** Harvest day

Results & Discussion

The sensors only worked properly in two replicates of the August planting, so sensor data represents the average of these two replicates.

Ambient Temperature

Control plots reached their highest average temperature (29.10°C) between 4:00 and 5:00 p.m. (Figure 5). Temperatures were lower under the solar panels than in control plots between 8:00 a.m. and 8:00 p.m., likely due to shading. The peak temperature under the panel was 27.26°C between 5:00 and 6:00 p.m., an hour later than the peak in the control plots. Shade cloth increased the average temperature relative to control plots between 9:00 a.m. and 6:00 p.m., reaching a peak temperature of 30.24°C between 1:00 and 2:00 p.m., 3 hours earlier than the control peak. A higher temperature under shade cloth compared to the unshaded control is contrary to the findings of Meena et al. (2014) that ambient temperature was 1.2-3.4°C lower under green shade cloth than in an unshaded control.

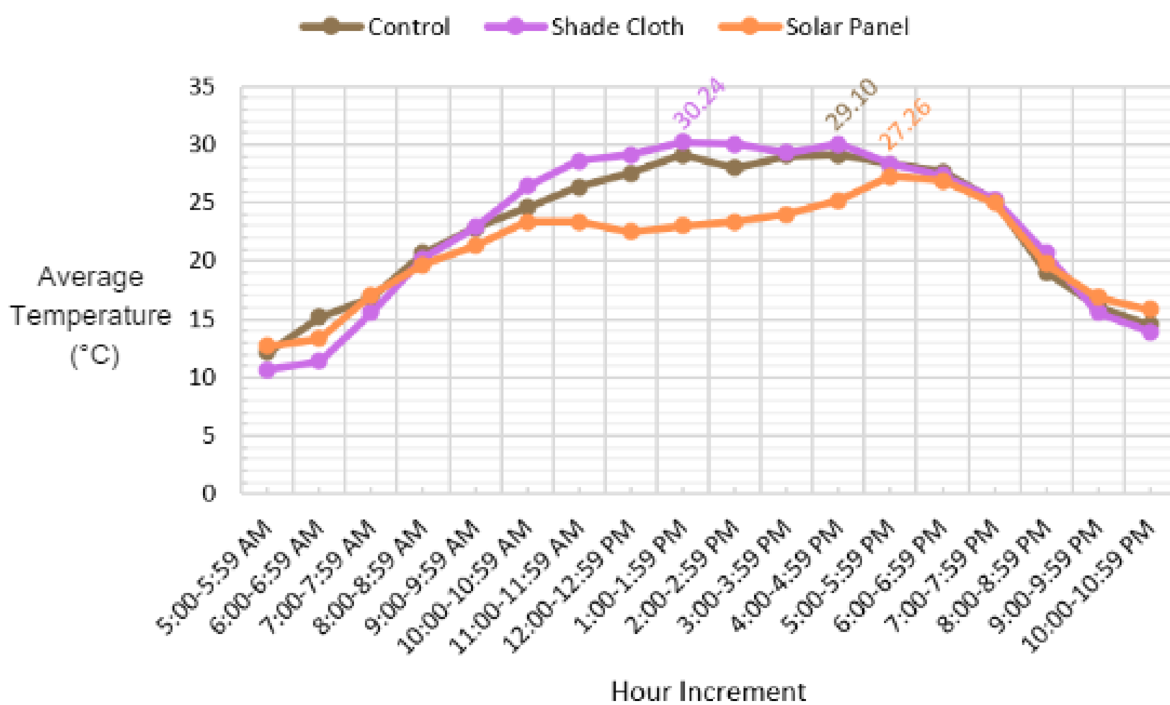

Figure 5. Average temperature (°C) under each shade method by hour increment. The highest average temperature (°C) in a given day is indicated for each shade method.

Soil Moisture

Soil moisture was lowest in control plots and highest in plots covered by shade cloth (Figure 6). This is consistent with the understanding that shade decreases both ambient air temperature and soil temperature, reducing soil moisture loss by evaporation and transpiration.

Soil moisture was stable throughout the day in control and solar panel plots, but tended to decline throughout the afternoon in plots covered by shade cloth (Figure 6). In the morning hours, the shade cloth held morning dew, keeping the soil moist until the afternoon when the dew evaporated and soil moisture decreased sharply. Meena et al. (2014) observed that relative humidity under green shade cloth was 0.5-7.2% higher than in unshaded controls.

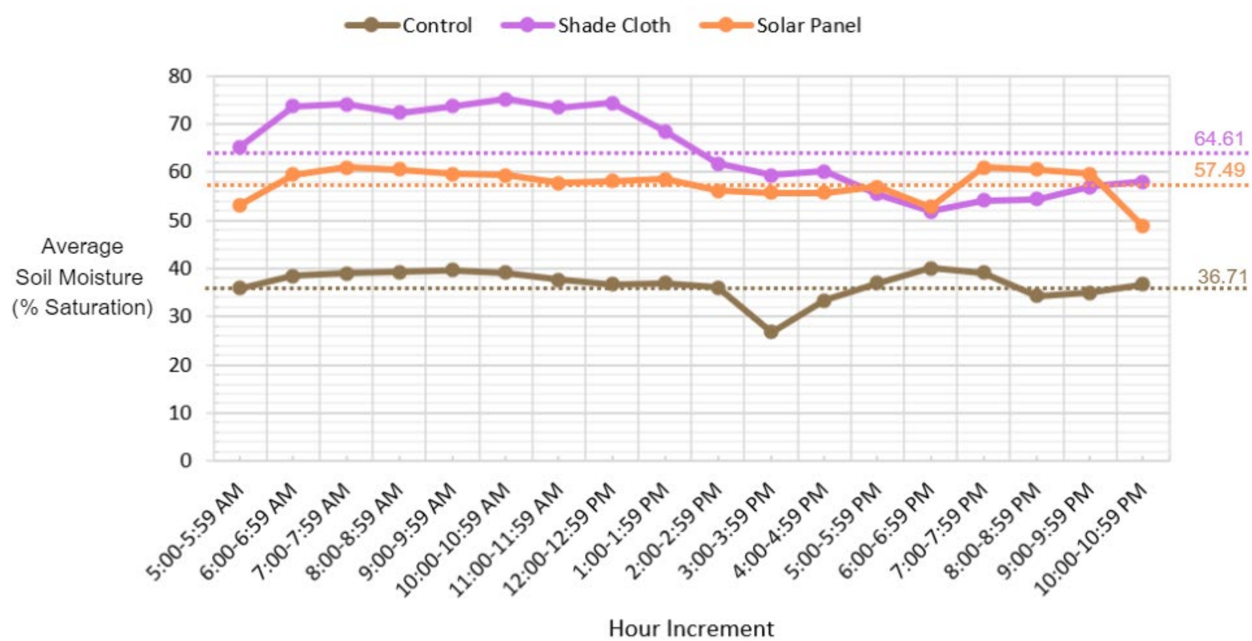

Figure 6. Average soil moisture (% saturation) under each shade method by hour increment. The daily average soil moisture is indicated for each shade method.

Solar Influx and Electrical Energy Production

The light data indicated that the solar panels could produce 11.0 kWh during the 23 days between Bok choy transplant and harvest (Figure 7, Table 1). Under BC Hydro's net metering program, electricity produced by grid-tied solar panels is worth CAD$0.06/kWh (BC Hydro, n.d.). Thus, each panel was estimated to produce CAD$0.66 worth of electricity over the span of 23 days in August.

Among the plots, the shade cloth plots captured more incoming light than the control plots, while the solar panel plots captured the lowest light. In Table 2, the effect of a solar panel's angle, the yield loss in light under the solar panel, and the effect of using shade cloth were calculated from Table 1. Having a horizontal solar panel in Richmond, BC during the growing months of July-August produces almost as much as a loss in electrical yield (3.4045 kWh) as it would be to put the horizontal solar panel in the shade (3.6666 kWh). However, this is likely because the light sensors were not flush with the top of the sensor housing unit so some of the incoming light was blocked (Figure S2). The 50% green shade cloth increased the light intermittence compared to the unshaded control, suggesting that the netting may reflect more light into the plot, whether it be because of the colour, the material, both, or some other combination of factors.

Meena et al. (2012) found that 40% green shade cloth had the highest peaks in reflectance of >20% in the 550-560 nm (green) of visible light spectrum among the shade cloths (black, green, red, white – all at 40% light blocking) tested as well as the unshaded control. Green shade cloth also had the highest peaks in reflectance at nearly 80% at 720-1360 nm (infrared). Additionally, they found that the green shade cloth lowered photosynthetically active radiation (PAR) by 65-76% compared to the unshaded control. This is consistent with Elad et al. (2007) who found that green shade net provided 37% PAR of that of no net. They also found that ultraviolet, blue, red, and far-red light intensity was lower under green shade net compared to when no net was present.

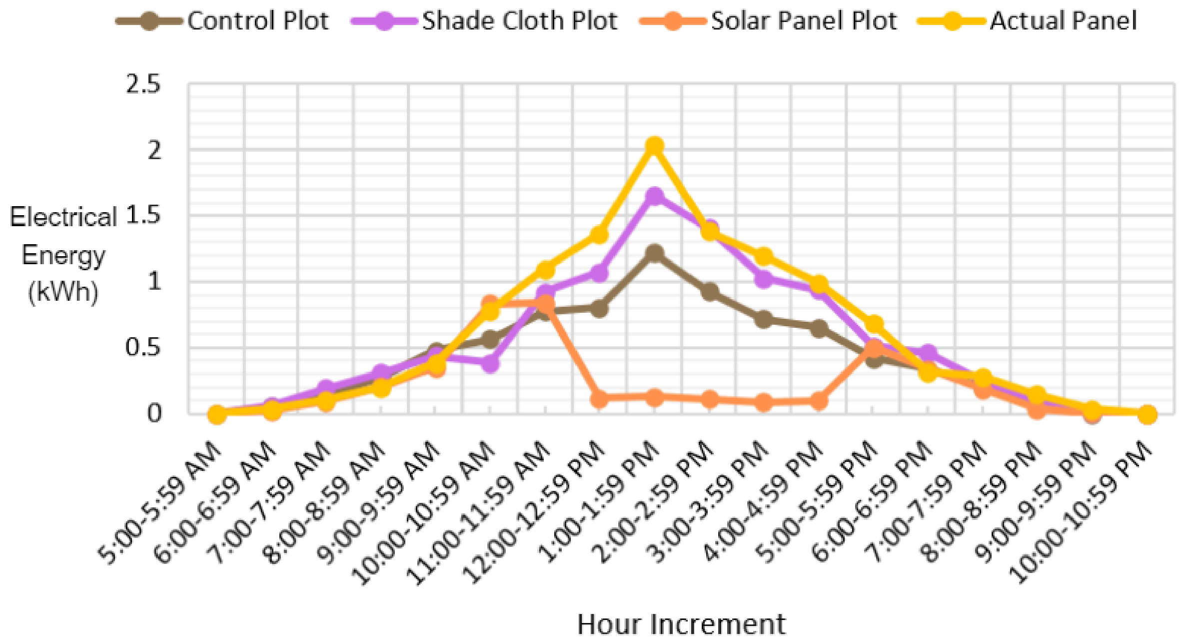

Figure 7. Estimated Electrical Energy (kWh) produced in each hour increment by each shade method plot or by the actual panel. Estimates taken by assuming that a 1 m x 1.7 m solar panel were placed on the plots or in place of the 'solar panel' and by assuming that the solar panel efficiency was 20%.

Table 1. Total kWh produced per plot or panel from Transplant day to Harvest day and the monetary value of the electrical output.

	Control Plot	Shade Cloth Plot	Solar Panel Plot	Actual Panel
Total kWh per plot/panel for 23 days (Transplant to Harvest)	7.6152	9.7259	3.9486	11.0197
Monetary Value (CAD$) at CAD$0.06/kWh	0.46	0.58	0.24	0.66

Table 2. Different factors having an effect on Total Electrical Energy (kWh) and its subsequent Monetary Value (CAD$).

	Total Electrical Energy (kWh)	Monetary Value (CAD$)
Effect of Angle on Light Intermittence (Actual Panel – Control Plot)	3.4045	0.20
Effect of Shading under Solar Panel (Control Plot – Solar Panel Plot)	3.6666	0.22
Effect of Shade Cloth on Light Intermittence (Shade Cloth Plot – Control Plot)	2.1107	0.13

Bolting

No Bok choy plants bolted during this study. According to Solomon (2007), mustard crops are highly sensitive to photoperiod, bolting easily when days are lengthening. Solomon recommends direct-seeding Bok choy in early spring in the Pacific Northwest for harvest before mid-May, when day lengthening triggers bolting. With shortening days further into the summer, sowing in mid-July will not cause the crop to bolt (Solomon 2007). In the past, KPU Farm direct-seeded Bok choy in rows using a Jang seeder and experienced bolting (Smith 2023). Direct-seeded Bok choy may be more susceptible to bolting than transplanted Bok choy, which was used in this study. However, Brave Child Farm in Surrey, BC, trialed transplanted Chun Mei alongside their usual variety Mei Qing Choi during the 2023 growing season (sown: May 29, 2023) and experienced faster bolting with Mei Qing Choi than Chun Mei, described as being on the verge of bolting (Millar 2023). While this study used seed blocks and wide plant spacing in 5x5 study plot set-up, Brave Child Farm used paper pots and transplanted in rows. In-row spacing was much tighter at Brave Child Farm than at KPU Farm, likely increasing competition for resources and the associated stress that could lead to bolting.

Marketable Yield

The data collected allowed analysis on the effect of Row on Marketable Yield, so Row was included as an independent variable.

The Mixed Model Analysis indicated that there was no statistically significant difference in Marketable Yield according to Shade Method, Planting Date, Shade Method * Variety interaction, Row * Variety interaction, and Variety * Planting Date interaction (Figure S2 of Supplementary Figures). Despite not being statistically significant, the mean marketable yield by shade method (Table 3) was used to calculate the mean marketable yield loss of Bok choy grown under the 'solar panel':

Average marketable yield loss under a 'solar panel' =

(marketable yield of control plots – marketable yield of 'solar panel' plots) * price/yield

The KPU Farm's farmer's market price for Bok choy in 2023 was CAD$6/lb. With this price, the average marketable yield loss of Bok choy under a 'solar panel' was:

(0.324 lb. – 0.249 lb.) * CAD$6/lb. = CAD$0.45

Table 3. Descriptives on Marketable Yield (lb.) of Bok choy by shade method.

	Shade Method	N	Missing	Mean	SE	Median	SD	Minimum	Maximum
Marketable Yield	Control	127	23	0.324	0.0187	0.315	0.210	0.00	0.980
	Shade Cloth	150	0	0.388	0.0182	0.395	0.223	0.00	0.997
	Solar Panel	146	4	0.249	0.0190	0.210	0.230	0.00	1.220

Twenty-three Bok choy plants were lost from the control plots across both plantings because birds removed the transplants – a common occurrence at the KPU Farm. Birds were still able to pull at the transplants while they were protected by a row cover for a week after transplanting, and after the row covers were removed. Fewer plants (n=4) were removed from the solar panel plots; the panel seemed to deter bird damage.

Major pests differed between plantings. Birds were the main pest in June, pulling out Bok choy transplants, and later pecking and damaging mature Bok choy plants. Aphids and subsequent viral infections were the main pests in August. Some plants were still removed by birds in August, but most of the missing plants were due to transplants not surviving to maturity. Bok choy plants protected by shade cloth had the lowest incidence of pest damage and the least viral infection symptoms.

Marketable yield differed by variety (Figure 8). White-stemmed varieties (Bopak, Joi Choi) generally had a higher marketable yield than green-stemmed varieties (Chun Mei, Mei

Qing Choi, Summer Zest). None of the test varieties had a significantly different marketable yield than the check variety, Mei Qing Choi. Chun Mei yield (0.360 lb/plant) was higher than that of Joi Choi (0274 lb/plant) (Table 4). Birds were more likely to remove white-stemmed Bok choy plants.

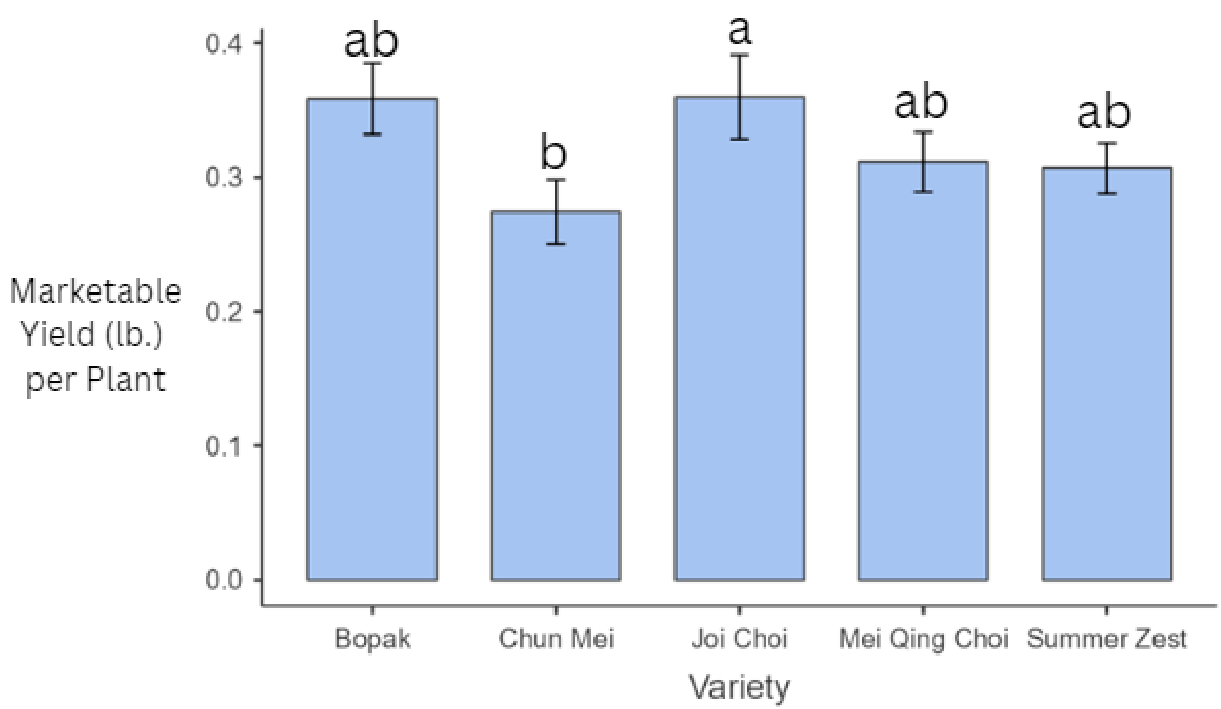

Figure 8. Marketable Yield (lb.) of Bok choy by variety. Summer Zest, Chun Mei, and Mei Qing Choi (the check variety) are green-stemmed varieties, while Bopak and Joi Choi are white-stemmed varieties. Different letters denote statistically significant difference between the means ($p<0.05$) with the Bonferroni correction. Error bars denote standard error.

Table 4. Descriptives on Marketable Yield (lb.) of Bok choy by variety.

	Variety	N	Missing	Mean	SE	Median	SD	Minimum	Maximum
Marketable Yield	Bopak	82	8	0.359	0.0265	0.356	0.240	0.00	0.980
	Chun Mei	86	4	0.274	0.0241	0.193	0.224	0.00	0.860
	Joi Choi	80	10	0.360	0.0314	0.360	0.281	0.00	1.220
	Mei Qing Choi	87	3	0.311	0.0222	0.300	0.207	0.00	0.720
	Summer Zest	88	2	0.307	0.0190	0.318	0.178	0.00	0.770

Rows A and B had higher marketable yield than rows C, D, and E (Figure 9). Plants in row E had insufficient water at the beginning of the June planting, which may have reduced yield. There was also a shade method*row interaction, because different patterns emerged by row when split by shade method (Figure 10). Shade from the solar panel likely reduced marketable yield in rows C, D, and E. Additionally, rows C and D in the solar panel plots were affected by bird droppings because the upper edge of the panel acted as a bird perch. Bird droppings made plants unmarketable. Row A had a higher yield in the solar panel plots than in other plots. This may be due to lower ambient temperature (Figure 5) and higher soil moisture (Figure 6) due to shade cast by the panel. However, yields tended to decline from rows A to E in control plots, too (Figure 10). For the shade cloth plots, a different pattern emerges: only rows B and E are significantly different from each other, but rows B and D generally had higher marketable yield than rows A, C, and E. This may be because drip lines were placed closer to rows B and D, providing extra moisture to these rows, while the whole plot benefited from higher light irradiance from the shade cloth (Figure 5).

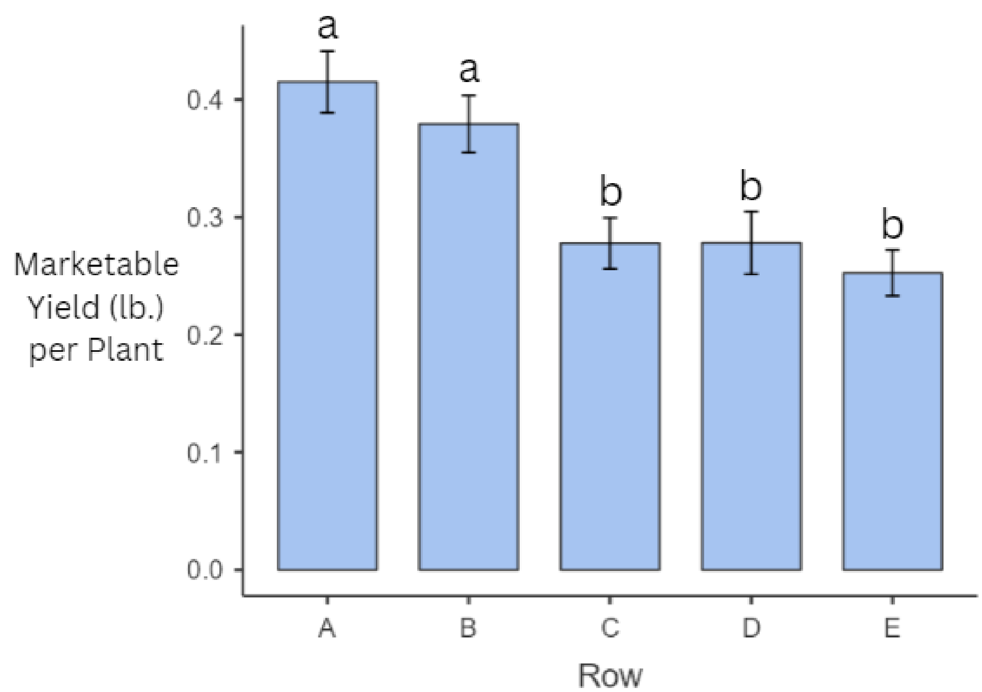

Figure 9. Marketable Yield (lb.) of Bok choy by row. For solar panel plots, Row A is furthest from the 'solar panel' while Row E is completely under the 'solar panel.' Different letters denote statistically significant difference between the means (p<0.05) with the Bonferroni correction. Error bars denote standard error.

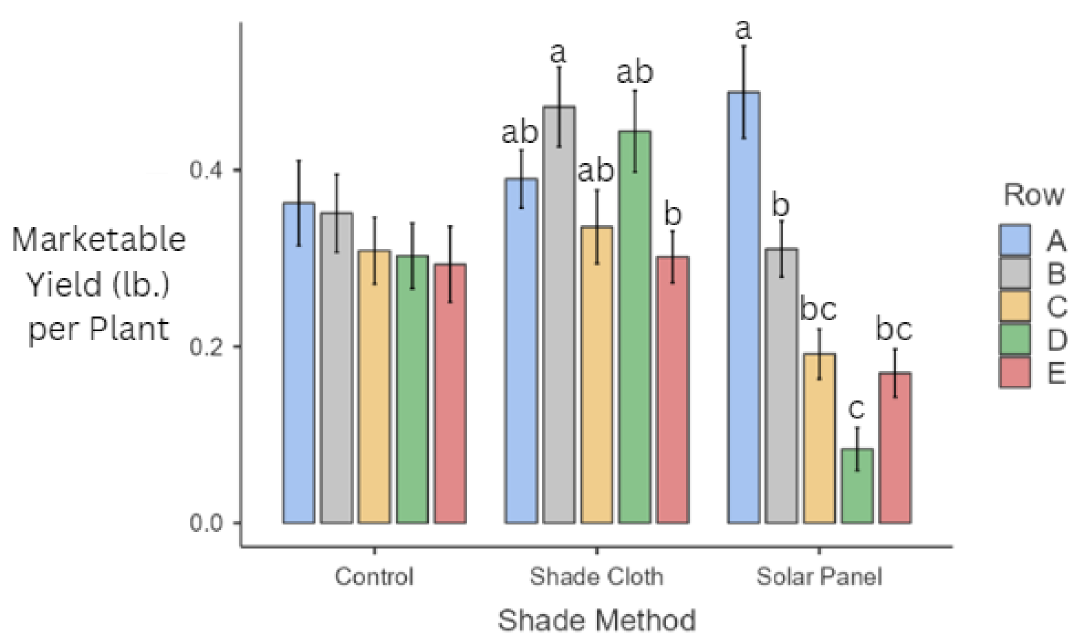

Figure 10. Marketable Yield (lb.) of Bok choy by row in each shade method. Different letters denote statistically significant difference between the means (p<0.05) within the shade method group with the Bonferroni correction. Error bars denote standard error.

Marketable yield was higher in control plots in June than in August , but no planting date effect was observed in other plots (Figure 11).

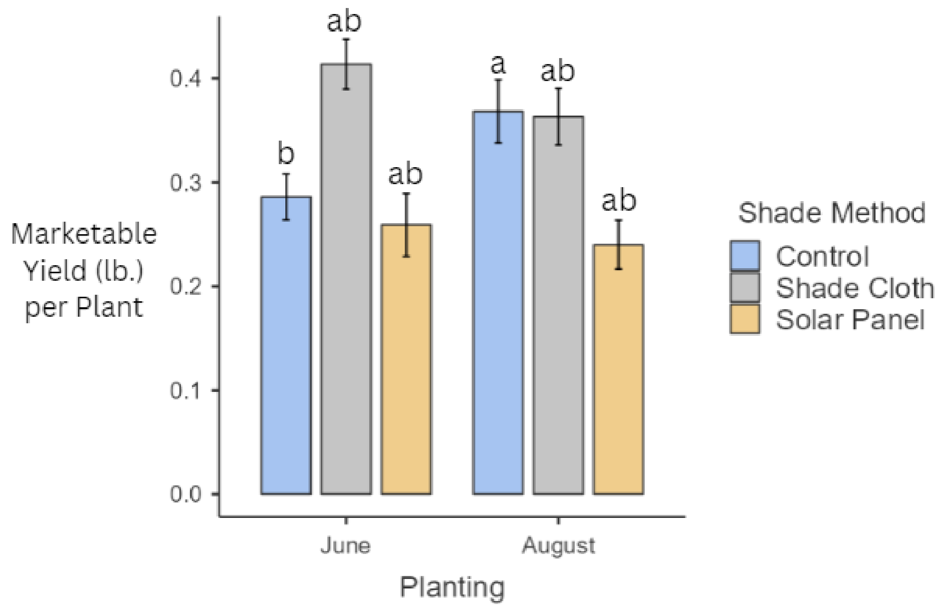

Figure 11. Marketable Yield (lb.) of Bok choy shade method in each planting date. Different letters denote statistically significant difference ($p<0.05$) between the means within and between planting dates when Bonferroni correction is not applied. When Bonferroni correction is applied, there is no statistically significant difference ($p<0.05$). Error bars denote standard error.

The row*planting date interaction was due to a trend of declining marketable yield from rows A to E in the June, but not in August (Figure 12). In August, the northern-most rows had higher marketable yield then the southern-most rows, but row C had the lowest marketable yield.

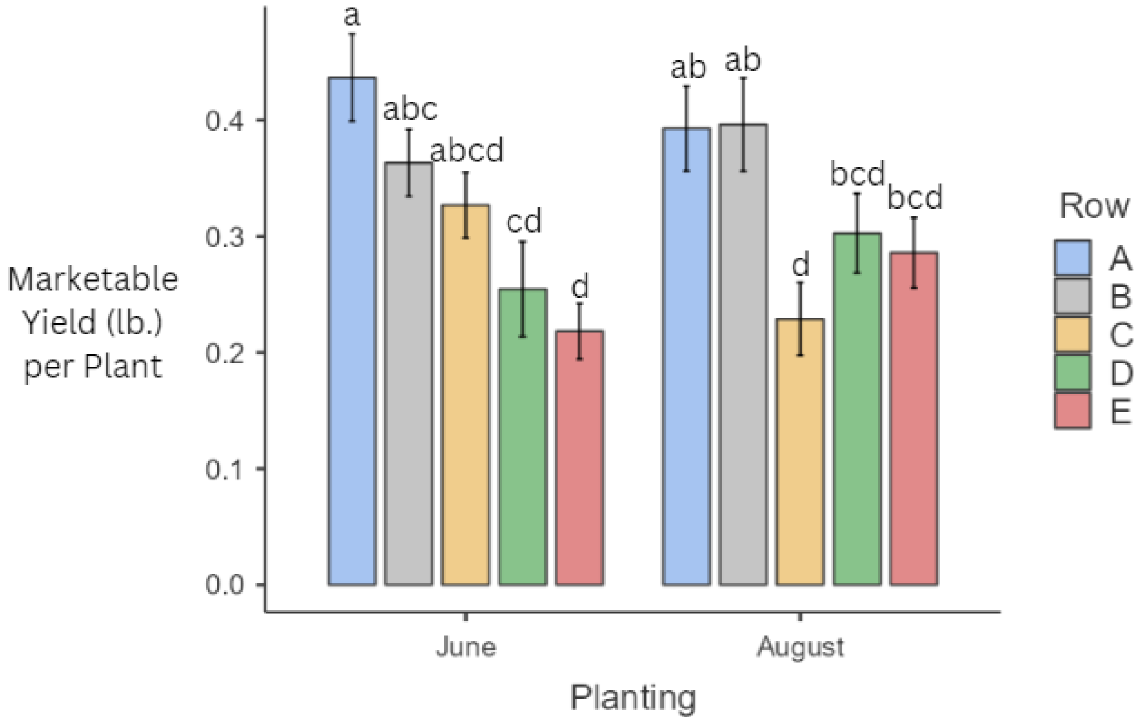

Figure 12. Marketable Yield (lb.) of Bok choy by row in each planting date. Different letters denote statistically significant difference between the means ($p<0.05$) within and between planting dates with the Bonferroni correction. Error bars denote standard error.

<u>Output by Shade Method</u>

Estimated electricity generation potential of the 'solar panel' during the growing period was 11.0 kWh, valued at CAD$0.66 (Table 1). This exceeds the CAD$0.45 yield loss in Bok choy due to lower light irradiance under the panel. Thus, ignoring the upfront cost of solar panel materials and installation, the electrical output of a solar panel compensates for the yield loss of Bok choy from shading it with the solar panel.

Monetary value of output by shade method is summarized in Table 5. Plots protected by shade cloth plots produced the highest value, followed by solar panel plots, then the control plots.

Table 5. Total Output and Total Value produced from Control, Shade Cloth, and Solar Panel plots.

	Control Plot	Shade Cloth Plot	Solar Panel Plot
Bok Choy Value (marketable yield * CAD$6/lb.)	1.94	2.33	1.49
Electrical Value (11.0 kWh * CAD$0.06/kWh)	N/A	N/A	0.66
Total Value (CAD$)	1.94	2.33	2.15

Conclusion

Marketable yield of Joy Choi was higher than that of Chun Mei but none of the test varieties differed significantly from Mei Qing Choi, the check variety. Neither shade method nor planting affected marketable yield and no bolting was observed. Row position within a plot did affect marketable yield, and this effect differed between shade treatments and between planting dates. An interaction between shade method and planting date was also observed.

Ambient temperature was highest in the shade cloth plots, followed by the unshaded control plots, then the ‘solar panel’ plots. Average soil moisture was highest in the shade cloth plots, followed by the ‘solar panel’ plots, then the unshaded control plots. Light irradiance at the soil level was highest in the shade cloth plots, followed by the unshaded control plots, then the ‘solar panel’ plots.

Although the effect of shade method on marketable yield was not significant, the numerical yield loss of Bok choy under the ‘solar panel’ was valued at CAD$0.45/plot, which was lower than the value of the electricity that could be generated by the panel, valued at

CAD$0.60/panel. Thus, the solar panel output could compensate for the yield loss of Bok choy shaded by the panel, ignoring fixed costs of solar panel installation. The total value of output was highest under shade cloth, followed by 'solar panel', and then unshaded control plots.

At a practical level, shade cloth outperformed the other shade methods because it produced the highest marketable yield (although not statistically significant), it produced the highest total output in terms of monetary value, it performed the best at protecting the Bok choy from bird, insect, and viral pests, and the upfront cost is cheaper than solar panels.

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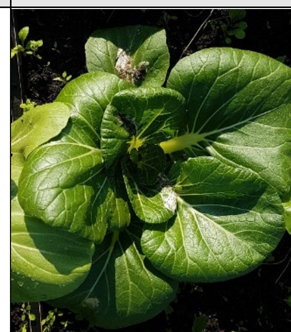
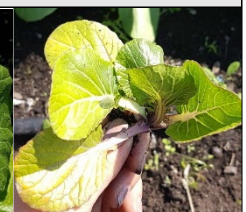
Appendix

Appendix A. Marketability Rating Scale

	RATING - Description	**Image Examples from June Harvest**
Poor Quality; *Not marketable*	1 – bird poop present; tiny size; destroyed by pests	  
	1.5 – small size, or extensive damage present	

Fair Quality; Edible but not appetizing; *Not marketable*	2 – small size, and/or many holes/blemishes	
	2.5 – small size, and/or some holes/blemishes	
Average Quality; Passable; *Marketable*	3 – presence of two+ leaves with large blemishes	

	3.5 – presence of one leaf with large blemish	
Good Quality; Few blemishes present; *Marketable*	4 – presence of 2-3 leaves with small blemishes	
	4.5 – presence of one leaf with small blemish	

Excellent Quality; No blemishes present; *Marketable*	5 – good size, shape, colour; no blemishes