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Passive Solar Greenhouse-A Sustainable Option for Propagating Sweet Potato for Colder Climatic Regions

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Abstract

Sweet potatoes (*Ipomoea batatas* L.) are nutritious and well adapted to a variety of growing systems around the world. This widely consumed root crop is propagated using cuttings, known as slips. Slips are predominantly cultivated in commercial settings, outdoors under field conditions, primarily in warmer regions, such as the southern states of the United States. Canada's slip production capacity is restricted due to its colder climate. Production of slips within a greenhouse system could prove to be a profitable enterprise for Canadian propagators and growers, especially with the availability of cost-effective greenhouse technology to support efficient slip production. A 2-year study was conducted at Assiniboine Community College, Brandon, Manitoba, Canada (49°N, 99°W). in 2019 and 2020, in a controlled commercial greenhouse (C1) with two passive solar greenhouse systems (PS1 and PS2) to determine the most efficient and economical way to produce slips commercially. The results from this study indicate passive solar greenhouse, PS1 and PS2 greenhouse technologies, produced comparable numbers of sweet potato slips (286.5, 273.3 per square meter respectively) compared to commercial standard greenhouse C1 (278.8). Days to sprouting of slips between C1, PS1 and PS2 greenhouses differed significantly ($P<0.05$). However, slip growth parameters, including number of nodes, stem diameter and total marketable slips produced in each greenhouse were not significantly different between C1, PS1 & PS2 greenhouses. In conclusion, local slip propagators can use PS1 and PS2 passive solar greenhouses to grow affordable, quality slips for sweet potato growers for timely field production in Canadian growing regions. Additionally, implementation of adapted passive solar greenhouse systems underscores the advancement of passive energy-based technology, which not only diminishes environmental repercussions but also offers year-round production alternatives.

Keywords: *Ipomoea batatas,* vegetative propagation, northern climate, greenhouse technologies

1. Introduction

Sweet potato (*Ipomoea batatas* L.) is a warm-season root crop grown mainly in tropical and subtropical regions (Iese et al., 2018). The crop requires a long frost-free period and relatively high soil and air temperatures to produce quality root yields (Teow et al., 2007). Sweet potatoes, a rich crop in anti-oxidants, fiber and vitamins, have increased in popularity among Canadian consumers in recent years. In Canada, due to climate challenges, sweet potato production is limited in crop growing regions as production is affected by lower temperatures and a shorter growing season, and limited access to propagation material. When comparing Canadian crop production areas, the province of Manitoba has a shorter, colder, climate having 75 to 125-135 frost-free days, which, are a major restrictive factor for commercial production of many field vegetables. However, some warm season crops with shorter maturity and amended agronomic practices can be grown as fresh produce in Manitoba. There is a significant and increasing interest in expanding commercial sweet potato production in Western Canada (Vanraes, 2016 & Walker, 2018). Sweet potato consumption in Canada has been steadily increasing and most consumer supply is imported from the United States (Agriculture and Agri-Food Canada, 2019). Canadian sweet potato production volume increased 30.5%, (12953 tonnes 2018 to 16883 tonnes in 2022). There has been a 22.7 % increase in imports over the last 5 years, from 66,240 tonnes (2017) to 81,274 tonnes (2021) (Statista, 2022). Canadian production has also increased and reached 2810 acres (2022) up from 1793 acres (2018) (Statistic Canada 2023 & OMAFRA 2023). According to Plant the Seeds: Opportunities to Grow Southern Ontario's Fruit and Vegetable Sector report, Ontario produces slightly more than 53,000 tonnes of sweet potatoes annually

(Greenbelt Foundation. 2021). As per the report, in October 2019, the average Canadian import price on US sweet potatoes was $0.46/pound, whereas Canadian sweet potatoes averaged at over $0.50/pound on the market.

There is significant potential to offset sweet potato slip imports and support industry expansion by local production. However, there are several factors and challenges that limit slip production expansion and competitiveness of sweet potatoes in Canada. Among these challenges, growers must be able to cultivate, store, and transport sweet potatoes into distribution channels in a financially viable manner, all while keeping prices closely aligned with those of imported sweet potatoes in the United States. One of the most immediate challenges for Canadian growers is to limit reliance on the US for slips (Young, M. 2020). However, this is contingent upon the local availability of slips for local growers. In the US, the sweet potato slip supply provided by commercial growers, are seeded into open fields in spring. This is not an option for Canadian slip propagators due to climatic conditions. As a result, there is very limited commercial sweet potato slip propagation in Canada. Canadian growers must import slips from the US to transplant into production fields in early June. Shipping losses are common and results in financial losses while impacting opportune seeding timetables. Increasing capacity for local slip propagation will provide Canadian sweet potato growers access to quality slips at the optimum cropping/planting time while eliminating transportation and administration costs, quarantine requirements and shipping losses.

Passive solar greenhouse has played a significant role in production of leafy and cool season vegetables in during winter months but also helped in extending the growing season in template area (Angmo et. al. 2019) and has now a common practice to raise vegetable nurseries in spring and grow leafy vegetables during winter months. Ahamed et. al (2018) studied the conceptual design of conventional greenhouses, using five different shapes of greenhouses including even-span, uneven-span, modified arch, vinery, and quonset shape for Canadian Prairies using a heating simulation model and concluded that uneven-span gable roof shape receives the highest solar radiation, whereas the quonset shape receives the lowest solar radiation. Similarly, Angmo et. al. (2019) evaluated different passive solar greenhouse structures such as Chinese style, trench, polytrench, polyench, polycarbonate, and polynet with a need to improvise economically viable and technologically feasible greenhouse design for crop production in winter season. Dolma et. at. (2023) studied two different sized passive solar greenhouses and found that a large size greenhouse performed better than small greenhouse size greenhouse as the larger greenhouse maintained 1.5±0.3 to 7.4±2.1 ℃ warmer during daytime, and 0.6±0.1 to 1.5±0.8 ℃ warmer at night and recommended large passive solar greenhouses for farmers in high altitude trans-Himalayan Ladakh regions for growing cauliflower and cabbage in winter season. Similarly, Ahamed et. al (2018) concluded that in high northern latitudes, east-west oriented greenhouse with more than 1 length-width ratio is more energy efficient and heating energy saving potential of the large span width in single-span greenhouses is relatively higher as compared to the multi span greenhouses. Angmo et. at (2020) study also suggested that cabbage can be successfully grown under improvised passive solar greenhouse during severe winter months in the trans-Himalayan Ladakh region. Research on the energy-intensive greenhouse production of sweet potato slips is limited, as indicated by a study conducted in Ontario (Valerio and Pearson, 2020). This study represents the inaugural investigation into the propagation of sweet potato slips within the PS1 and PS2 passive solar greenhouse technologies in the Canadian environment. The data obtained from this research holds substantial value for those contemplating the adoption of PS1 and PS2 passive solar greenhouse systems for slip propagation, serving as a valuable resource for potential slip propagators in colder climates. This study suggested the necessity for further research aimed at reducing input costs and enhancing slip yield to bolster profit margins, especially among greenhouse slip producers and commercial growers. The objective of this research is to a) evaluate the production of sweet potato slips within various passive solar greenhouse systems, each characterized by distinct technological inputs with an aim to generate and distribute locally propagated, high-quality planting material to Canadian growers timely and at a competitive price point b) adoption of passive solar greenhouse technology, with reduce environmental impact, providing year-round crop production option for Canadian growers.

2. Material and Methods

2.1 Experimental Site

A two-year study was conducted in three technology different greenhouses at Assiniboine Community College, Brandon, Manitoba, Canada (49^{o}N, 99^{o}W). in 2019 and 2020. The 10-yr average normal climate for Brandon is as follows: mean temperature varies from −22 ℃ to 25 ℃; frost-free days is between 105 and 115 and growing season precipitation is 373 mm (source: Environmental Canada Weather Station, Brandon Meteorological Station (ID: CA005010490)).

2.2 Description of Greenhouse

This study evaluated sweet potato slips production performance in in three physically attached but separate greenhouse sections with different design technologies. Sweet potato cultivar "Covington" was used in a single-factor independent experiment. The treatments were (i) commercial greenhouse, with high technology inputs, named C1, a standard A-frame greenhouse features (triangular, cross-rafters with a peak) and advanced control of climate due to supplemental heating and lighting (mix of 400 W metal halide lamps and 400 W high-sodium pressure lamps in alternate rows); (ii) passive solar greenhouse, with medium technology inputs, named PS2, a half-dome structure with a passive solar system in addition to in-floor heating, consisting of standard passive solar greenhouse features but warmer due to better heat sinks; and (iii) passive solar greenhouse, with low technology inputs, named PS1, a half-done structure with a passive solar system, three-layer transparent polyethylene glazing material with basic features (Abbey and Rao. 2018). The passive solar greenhouses, PS1 and PS2, were designed to collect, store, and distribute solar energy in the form of heat in the winter and dissipate heat in the summer. The main components of both (PS1 and PS2) greenhouses included steel framing, a three-layer transparent polyethylene film, a north wall for conserving solar energy, and one hydronic unit heater (Model: RH165HO1SAB Zehnder Rittling, NY USA) connected through glycol loops to a propane fueled boiler (Camus DynaMax DMPG-0701-MSI, Mississauga, Canada), configured with Argus Titan Control system to maintain target temperature(s). The south side of both greenhouses features a sloping 45^{o} facing steel framing structure resting on a 1.2 m high concrete insulated vertical wall. The surface is glazed with Solawrap, a three-layer transparent polyethylene film, with air bubbles in the middle acting as energy-saving insulation (Growing Technologies, Solawrap Canada), which has a solar radiation transmissivity of 0.83. The east and west walls were covered with 6 mm Macrolux twin polycarbonate (0.80 solar radiation transmissivity) constructed with 15.2 cm studded insulated wall. The north side interior wall is insulated and covered with 24ga black painted steel material (Cascadia Metals Ltd). PS1 has an extended floor area equipped with rows of 8 black PVC barrels (95 gallons capacity) to conserve solar energy. However, this variable was not used in this study. In addition to PS1 heating features, PS2 received additional floor heating from the active solar heating panels, 5 sets of 30 SunMax Vacuum Heat Pipe solar evacuated tube collectors, installed on standing extruded aluminum frame (2.6mx2.0m) in front of the south facing greenhouse complex. These solar collectors absorb and transfer heat to the solar hot water tank (StorMaxxCTec-211-3HX) installed in PS2. The in-floor heating system draws energy from the solar hot water tank to heat PS2. The C1 on the other hand, was designed to meet industry standards with relatively high technological input and was glazed with double-layer semi-rigid polycarbonate. Unlike the PS1 and PS2, the environmental variables in the C1 were fully controlled. Experimental area on greenhouse bench measured, 2.6mx0.8mx0.8m (LxWxH), and were the same for all three greenhouses.

2.3 Greenhouse Temperature Setting and Data Acquisition

Both external and internal greenhouse environmental conditions were controlled and recorded using Argus Titan system version 718 (Argus Control Systems limited, Surrey, British Columbia, Canada). Titan WS2 weather station, installed at the top of greenhouse building, was configured with the Argus Titan Control System to record on-site weather data for outdoor temperature (℃), light energy (W/m^2), wind speed and direction. Inside greenhouse climate information were recorded by Titan I/O modules (Omni-Sensors SEN-OSM-1.3A), installed at the same distance in each greenhouse. Data recording included climate temperature (℃), climate humidity (% RH), and Photosynthetically Active Radiation (PAR µmol) and CO_2 (ppm). The temperature profile for all three greenhouses was set at 20 ℃ (day) and 18 ℃ (night) from March to May. Argus control system was configured to deliver the amount of heat required to match the current rate of the heat loss to maintain the target temperature. This configuration calculates Heating Required Temperature (HRT %). HRT considers current temperature conditions in relation to the target set point temperature and develops a proportioned result from 0% to 100%. At 0%, no heat is required for temperature management. Whereas at 100%, maximum heating resources are required to meet the current demand (Rao, et. al. 2018).

2.4 Plant Materials and Data collection

The sweet potato cultivars Covington (COV) was used to evaluate slip production in all three greenhouses. Generation 2 (G2) US grade # 2 root seed was bedded into four black plastic crates, measuring 60 × 38 × 22 cm (L×W×H) from March to early June in each greenhouse to produce G2 slips. Black landscape fabric, 1.5 oz non-woven, lined the bottom and sides of the black plastic crates to hold the Pro-mix BX^{TM} soilless potting medium (Premier Horticulture Inc., Quakertown PA) and roots. Moistened pro-mix layer of 10 cm was spread evenly in the black plastic crates. Seed roots of sweet potato cultivars were distributed evenly and placed manually on 01 March 2019 and 2020 at equal covering seed root density in each crate without overlapping or stacking, providing optimum sprouting potential. Seed roots were covered with 4 cm of moistened pro-mix layer in crates after planting. N17-P5-K19 soluble fertilizer was applied every two weeks at the rate of 1.16 g-1 per crate after sprouting started. Plants were watered as required.

Data included recorded slips production and growth characteristics, including days to sprouting for all four crates from each greenhouse. Harvesting of slips, that attained the length of 25 cm or greater, was completed three times, May 25th, June 1st and June 8th. Manual harvesting was completed by cutting vine stems 1 inch above the soil line. Slips were harvested in the morning and data collection was conducted on the same day. Harvests from each greenhouse were sorted and measured to determine the number of marketable slips produced per square meter. In addition to slip yield, slip quality parameters including number of nodes and stem diameter were measured on 10 individual, randomly selected slips from each replication at each greenhouse in 2019 and 2020 and averaged for analysis. Slip quality measurements (stem diameter and number of nodes) were performed on a randomly selected individual slip. Slip length was determined by measuring from the cut end to the apical meristem. The nodes of each sample were counted from the cut end to the apex, but did not include the growing point. Slip stem diameter was measured, using a caliper tool, within 1 cm of cut end and nodes were avoided. Data was averaged for comparison and analysis.

2.5 Experimental Design and Data Analyses

The treatments were greenhouse design technologies, C1, PS1 and PS2, and with 4 crates of each sweet potato cultivar randomly interspersed on the benches in each greenhouse. To avoid pseudoreplication as explained by Schank and Kohnle (2009), the experiment was replicated in time i.e. two replications in 2019 and 2020. Data were subjected to analyses of variance (ANOVA) using CoStat (ver. 6.45; CoHort Software CA U.S.A). Differences between treatment means were determined using Fisher’s least significant difference (LSD) at 0.05.

3. Results and Discussion

Monthly minimum, maximum and average outside air temperatures and light conditions varied between years 2019 and 2020 from March to May. Minimum, maximum and average monthly outside air temperatures were higher in year 2019 and slightly warmer than 2020. Whereas, outside light energy trends were higher for the month of March, in 2020, and there was more light energy in April and May 2019 compare to 2019 (Table 1). Overall, there was an observed upward trend in both outside air temperatures and light conditions from March to May. During this period, the crop experienced an augmentation in heat accumulation and photosynthetically active radiation, which contributed to its growth in each consecutive month.

In this study, all three greenhouse technologies (C1, PS1 and PS2) created varied microclimates (Fig. 1) and had a different influence on HRT (Fig. 3) and days to sprouting of sweet potato slips (Fig. 4) in particular. Similarly, varied microclimate recorded by Ahmad et. al (2023) while studying on design and thermal performance of innovative greenhouse and reported that the solar greenhouse ensures proper microclimatic conditions all day long by reducing the temperature by 11.14 ℃ compared to conventional greenhouses. Maximum and minimum temperatures exceeded set points in all greenhouses in both study years from March to May, excluding PS1 greenhouse where minimum night temperatures remained below set setpoint in March (14^{o}C) and April (16^{o}C) in 2019 and was off set points for minimum and maximum temperatures in March (12^{o}C and 16^{o}C respectively) 2020 (Table 2 and Fig. 1). PS2 greenhouse maintained a higher mean temperature (22.9^{o}C) in the month of March compared to C1 (22.1^{o}C) and PS1 (20.0^{o}C) greenhouse technologies (Fig. 1). The temperatures in all three greenhouses created varied climatic conditions and affected sweet potato sprouting differently in each greenhouse. The results were statistically significantly ($P<0.05$) different for days to sprouting in greenhouse technologies tested in this study (Table 5). The increase in greenhouse climate temperature in PS2 observed in this study, was possibly due to the concrete floor and in-floor heating solar heating system in PS2, differentiating from PS1 and C1 greenhouse technology as reported by Rao et al. (2018) in a passive solar greenhouse studied in the Canadian prairies (50^{O}N). A similar study was conducted by Bazgaou et. al. (2021) on the performance of an Active Solar Heating System (ASHS) consisting of two solar water heaters equipped with flat solar collectors, two storage tanks and exchanger pipes, and assesses the performance of the Active Solar Heating System, climatic and agronomic parameters in two identical canarian greenhouses, one equipped with ASHS heater and the second without. Results from this study showed that the ASHS system improve the nocturnal climatic conditions under greenhouse, and the economic analysis indicated that the ASHS system is a cost effective in terms of investment and energy saving.

Table 1. Two years monthly average outside temperature (°C) and light energy (Wm-^{2}) at experimental site

Month	2019			2020			2-Years Average		
	Outside Temperature (°C)								
	Min[1]	Max[1]	Mean[1]	Min[1]	Max[1]	Mean[1]	Min[1]	Max[1]	Mean[1]
March	-16.0	9.0	0.0	-18.9	3.4	-5.9	-17.5	6.2	-3.0
April	-4.0	11.0	3.9	-7.9	6.0	0.2	-6.0	8.5	2.1
May	3.0	22.0	11.5	2.9	18.2	11.3	3.0	20.1	11.4
	Outside Light Energy (Wm-^{2})								
March	25.0	200.0	104.4	61.0	226.0	150.1	43.0	213.0	127.3
April	75.0	291.0	199.0	24.0	285.0	178.9	49.5	288.0	189.0
May	54.0	389.0	258.6	38.0	327.0	183.3	46.0	358.0	221.0

[1] average measured daily over 3 hours interval for each day of the month.

Table 2. Monthly average inside climate temperature variations (°C) in C1, PS1 and PS2 greenhouses for two study years

Month	2019						2020					
	C1		PS1		PS2		C1		PS1		PS2	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
March	23.0	21.0	22.0	14.0	26.1	18.9	24.4	21.6	23.6	12.6	26.8	20.8
April	23.0	21.0	25.0	16.0	26.9	17.5	25.1	22.1	23.5	21.8	26.1	21.2
May	27.0	21.0	29.0	22.0	30.4	21.8	25.6	22.4	27.8	21.3	30.3	21.7

Table 3. Monthly average photosynthetically active radiation (µmoles m-^{2}s-^{1}) variation in C1, PS1 and PS2 greenhouses for two study years

Month	2019						2020					
	C1		PS1		PS2		C1		PS1		PS2	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
March	114.0	20.0	101.0	8.0	194.0	15.0	130.0	39.0	111.0	0.0	209.0	28.0
April	162.0	59.0	130.0	15.0	250.0	38.0	175.0	19.0	126.0	6.0	253.0	16.0
May	186.0	37.0	137.0	13.0	275.0	30.0	176.0	26.0	136.0	9.0	264.0	21.0

Table 4. Monthly heating temperature required (%) variations in C1, PS1 and PS2 greenhouses for two study years

Month	2019						2020					
	C1		PS1		PS2		C1		PS1		PS2	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
March	38.0	11.0	90.0	14.0	20.6	15.1	57.5	10.9	66.9	3.3	67.6	6.1
April	27.0	6.0	92.0	24.0	21.6	4.8	37.2	11.1	75.7	25.3	62.3	11.7
May	30.0	0.0	67.0	3.0	12.9	0.0	19.9	1.3	43.2	2.1	20.8	0.2

Starting from March 2019, there was a rise in photosynthetically active radiation (PAR) within all three greenhouses, corresponding to an increase in outside solar radiation levels. (Table 3). PS2 greenhouse recorded significantly ($P<0.05$) higher PAR over C1 and PS1 in each month and between months for the individual growing seasons (Fig. 2). The highest PAR intensity was measured in PS2 (275) in the month of May 2019, followed by C1 (186) and PS1 (137) respectively. A similar trend of higher PAR was recorded in PS2 greenhouse for the month of April and March for the year 2019 and 2020 compare to C1 and PS1 greenhouse technologies (Table 3). This higher PAR in PS2 greenhouse technology, as reported by Rao et. al 2018, resulted from the concrete floor reflection as compared to the interceptive gravel floor in the PS1 and in C1 greenhouses. This may also have contributed to higher maximum temperatures in PS2 as solar radiation had more influence in the greenhouse temperature compared to outdoor temperature (Beshada, 2006). Zhang et. al. (2021) reported the direct solar radiation flux and net radiation flux on building surface areas changed significantly while studying the influence of urban three-dimensional structure and building greenhouse effect on local radiation flux. The absorption of the diffused light by the gravel floor surface was also in agreement with the studies carried out by Papadakis et al., in 2000. Tao et. al (2016) evaluated the light distribution and its effect on plant growth in Chinese Solar Greenhouse (CSG), and showed that PAR intensity in the south and middle sections of CSG was permanently higher than the north section which resulted in distinct plant growth performance. Specifically, plants grown in the north section of CSG exhibited a shade avoidance response with stem elongation phenotype and leaf expansion. Furthermore, the north-plants showed lower leaf photosynthetic capacity which correlated with a lower total nitrogen and chlorophyll contents in comparison with the plants grown in the middle and south sections. Tao et. al (2016) concluded that due to heterogeneous light distribution plant growth is not uniform in CSG, which was caused by unbalanced greenhouse structures and inputs. The results of the present study agree with Rao et al. (2018) who reported higher photosynthetically active radiation in a concrete floored greenhouse compared to a gravel floored greenhouse and influenced the microclimate of the greenhouse.

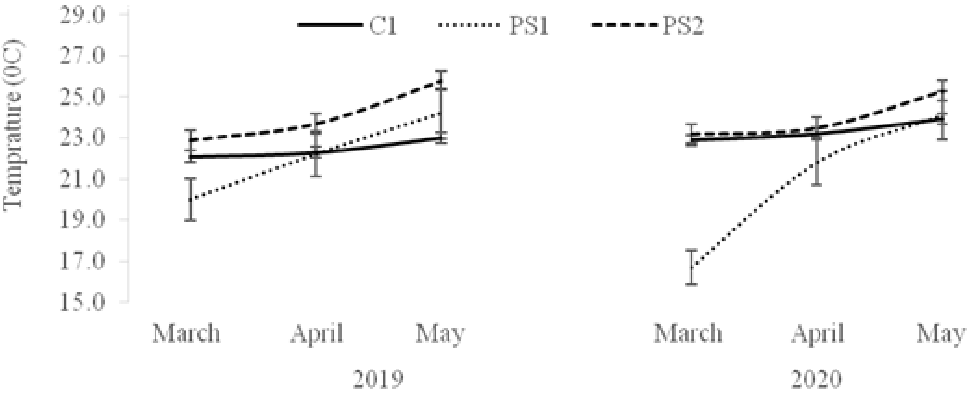

Figure 1. Greenhouse climate Temperature variations in C1, PS1 and PS2 greenhouses

Vertical bars ±SE (n=240, 248, 248, 224, 248, 240 for March, April and May respectively)

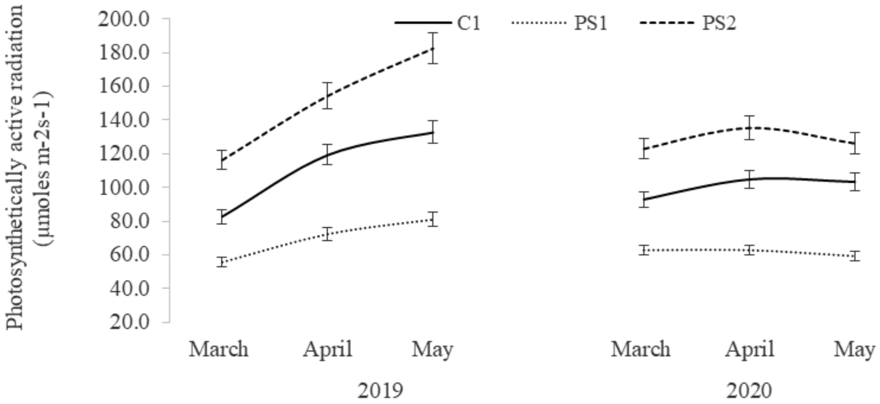

Figure 2. Photosynthetically active radiation variations in C1, PS1 and PS2 greenhouses

Vertical bars ±SE (n=240, 248, 248, 224, 248, 240 for March, April and May respectively)

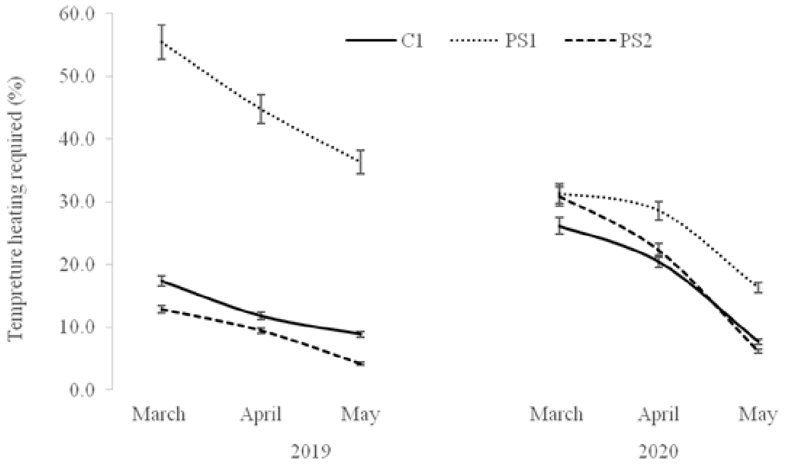

Figure 3. Temperature heating required (%) variations in C1, PS1 and PS2 greenhouses

Vertical bars ±SE (n=240, 248, 248, 224, 248, 240 for March, April and May respectively)

The required heating temperature for each C1, PS1 and PS2 greenhouse was measured daily over two years. Yearly averaged, maximum and minimum HRT was recorded and presented in Table 4 and Figure 3. PS1 required significantly higher heating (55.5%, 44.8% & 36.4% and 31.3%, 28.3% & 16.3%) in for March, April and May respectively for both years, in order to maintain inside temperature compared to PS2 and C1 greenhouses. Whereas a non-significant heating requirement was recorded between the PS1 and C1 greenhouses for the month of March 2020 (Fig. 3). This lower demand of required heating in PS2 resulted from high temperatures generated through the combined climate energy effect, outdoor temperature and light effect, average daily energy storage and release by the north wall and soil surface (Beshada et al., 2006) and in-floor heating system as reported by Rao et. al. (2018); consequently, maintaining a higher climate temperature in PS2 than C1 and PS1. Rao et al. (2018) additionally noted a considerably reduced influence of outdoor heating temperatures in April as compared to March. Moreover, they observed a non-significant disparity in the heating light effect between the months of March and April while investigating the implications of solar energy on greenhouse climate and crop production. Similarly, Gupta and Chandra (2002) conducted research to explore different energy conservation measures for the establishment of an energy-efficient greenhouse. Their findings revealed a 2.6% and 4.2% reduction in heating requirements for gothic arch-shaped greenhouses compared to gable and Quonset shapes, respectively. They also reported an additional substantial heating reduction of 23% and 30% through the implementation of double wall glazing and insulation on the north wall of the gothic greenhouse. Xu et. al. (2021) compared passive solar greenhouse heating with and without active solar water wall and reported 4.1 ℃ higher night time temperature than that in the control greenhouse and conclude that retrofitting the water wall into Chinese solar greenhouses can make warm-season crop production feasible throughout winter by eliminating supplemental heating and supported the present finding of this study.

Table 5. F ratios and effect of greenhouse technology on sweet potato slips production and growth characteristics evaluated during 2021 and 2019 (2 years Average)

	Days to sprout	1st harvest	2nd harvest	3rd harvest	Total Marketable Slips	Nodes (no. /cm.)	Stem Diameter (mm)
Greenhouse	Means						
C1	29^{c}	69.2^{ab}	90.0^{a}	128.6^{a}	287.8^{a}	9.8^{a}	3.38^{a}
PS1	35.1^{a}	63.25^{b}	88.7^{a}	121.7^{a}	273.7^{a}	10.5^{a}	3.34^{a}
PS2	30.5^{b}	75.0^{a}	90.0^{a}	121.5^{a}	286.5^{a}	9.7^{a}	3.18^{a}
LSD	1.18	8.2	8.9	10.77	15.82	0.86	0.45
Source of Variation	Significance						
Year	*	NS	NS	NS	NS	NS	NS
Greenhouse Technology	***	*	NS	NS	NS	NS	NS
Year x Greenhouse Technology	NS	NS	NS	NS	NS	NS	NS
CV	3.56	11.28	9.46	8.27	5.32	8.21	13.24

*, **, *** represents P=0.05, 0.01, 0.001 respectively and ns, not significant

$^{a\text{-}b}$=means within a column followed by the same letter are not significantly different at P<0.05 according to LSD.

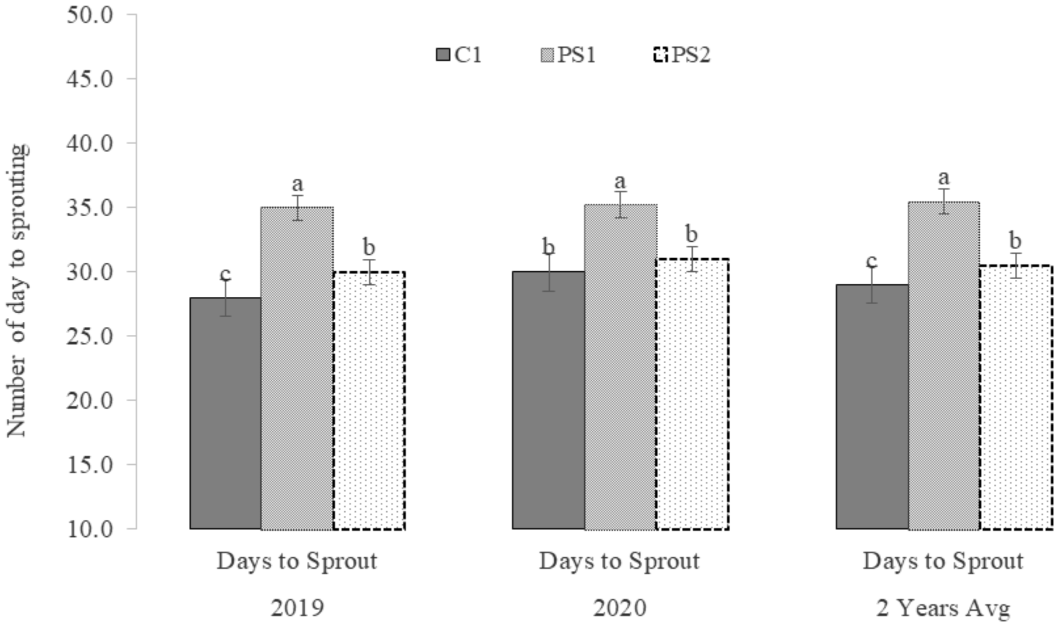

Figure 4. Sweet potato slip days to sprout in Commercial (C1), Passive Solar 1 (PS1) and Passive Solar 2 (PS2) greenhouses. Different letter on error bars indicate the dsignificant diffence (p=0.05)

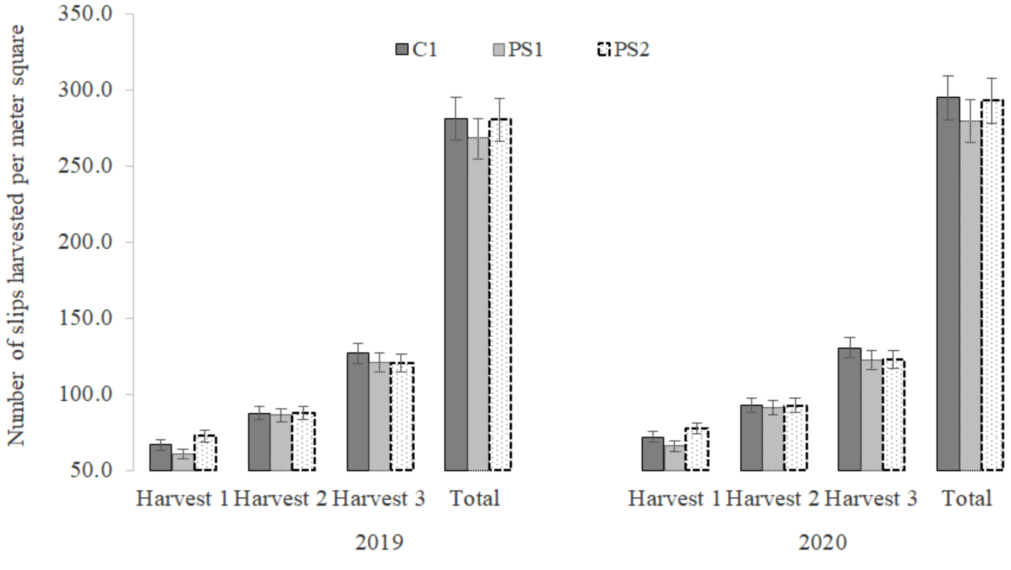

Figure 5. Marketable slips (m-^{1}) in Commercial (C1), Passive Solar 1 (PS1) and Passive Solar 2 (PS2) greenhouses. Different letter on error bars indicate the dsignificant diffence (p=0.05)

Sweet potato slips production and growth parameters in all three greenhouse technologies are presented in Table 5, and Figures 4 & 5. Analysis of variance revealed a significant (P<0.05) difference for days to sprouting between three, C1, PS1 & PS2, greenhouse technologies (Table 5). Sweet potato slips sprouted 5 to 6 days earlier in C1 greenhouse compared to PS1 greenhouse (Fig. 4). A higher minimum temperature of, 21^{o}C and 21.6 ^{o}C, was maintained in C1 during the month of March 2019 and 2020 respectively, which favoured early slips sprouting in C1 compared to PS1 where minimum temperatures was 14^{o}C and 12.6 ^{o}C during the month of March 2019 and 2020 respectively (Table 2). Significant difference (P<0.05) was recorded between C1 and PS2 greenhouse environments for the number of days to sprouting. A significant (P<0.05) difference was recorded for slips harvested on May 25th, 1st harvest, in PS1 greenhouse where lower number of slips were harvested comparing PS2 and C1 greenhouses, whereas, non-significant differences were found for the 2nd, 3rd harvests and in total number of slips harvested between the C1, PS1 and PS2 greenhouse technologies. Similarly, a non-significant difference was found for number of nodes and stem diameters of the slips harvested in each greenhouse. The two-way interaction between years and greenhouse technology was non-significant for all slip production and growth characteristics evaluated during this study (Table 5). The findings from the two-year study demonstrate that employing PS1 and PS2 greenhouse technologies provided a comparable advantage in slip production when initiating the process in early March to ensure that slips are prepared for transplanting by the beginning of June. This is evidenced by the presence of non-significant interaction of year versus greenhouse technology (Table 5).

Results from this study indicated all three, C1, PS1 and PS2 greenhouse technologies produced comparable (287.8, 273.3 and 286.5 respectively) numbers of sweet potato slips for field transplantation in early June. Gourdo et. at. (2019) studies on evaluating the effect of a solar heating system, using black plastic sleeves filled with water, on the greenhouse microclimate and tomato yield in canarian greenhouses and recorded 3.1 °C higher nighttime temperature inside the greenhouse compared to the control greenhouse and tomato production increased by 35% compared to the control greenhouse due to this microclimate improvement. Hoppenstedt et. at. (2019) compared two growing environments, high tunnel versus an open field for slip production and reported inconsistent slip yield from high tunnel when tested two years in a row. However, Hoppenstedt et. at. (2019) showed the result for mean comparisons for vine length and stem diameter of slips were not significantly different between high tunnel and open field systems in both tested years and thus support findings for the growth parameter evaluated in this study. Hoppenstedt et. at. (2019) also reported the mean high tunnel (120.3 slips/m2) and open field marketable slip (123.3 slips/m2) yield harvested in year 2017 were nearly the same and are like this current study's findings. Earlier investigations into sweet potato slip production, as documented by Valerio and Pearson (2020) in a conventional greenhouse setting, as well as studies carried out by Knewtson et al. (2010) in various growing systems, including high tunnels, align with the findings of this research. This research underscores that sustainable passive solar greenhouse technologies represent a viable choice for sweet potato slip production within the Canadian environmental context.

4. Conclusion

The results of this study suggest sweet potato slip production in PS1 and PS2 passive solar greenhouse technologies may be a viable alternative to produce sweet potato slips for Canadian growers. PS2 greenhouse design with an in-floor active solar heating system provided an optimum slip production environment as compared to PS1 greenhouse. PS2 with a lesser number of days to sprouting and higher total marketable slips give better option over PS1 greenhouse. PS2 greenhouse will also allow growers to reduce greenhouse heating expenses and maximize early and more slips production in PS2 greenhouse. Further research exploiting different planting dates and using different growing media is recommended to determine better methodology and material to optimise slip production in passive solar greenhouse conditions.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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