Acta Sci. Pol.
Formatio Circumiectus 22 (2) 2023, 79–92
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2023.22.2.06

ORIGINAL PAPER Accepted: 14.07.2023

GROWTH PERFORMANCE, PARTITION COEFFICIENT AND HARVEST INDEX OF WIDELY GROWN POTATO (*SOLANUM TUBEROSUM* L.) VARIETIES IN ETHIOPIA

Momina Aragaw[1]✉ 0000-0002-8040-5117, Wallelign Worku[2] 0000-0003-0367-306X, Tesfaye Abebe[3] 0000-0002-9510-6929

[1] Debre Tabor University
[2] Hawassa University
[3] Holetta Agricultural Research Center

ABSTRACT

Aim of the study
The main objective of the study was to compare the differences in growth performance, dry matter partition coefficient and harvest index of widely grown potato varieties.

Materials and Methods
The research was conducted at the Adet Agricultural Research Center, Ethiopia during the 2019/2020 and 2020/2021 main cropping seasons, using randomized complete block design for Shenkola, Belete, Gudenie, Guassa, Dagim and Ater Ababa potato varieties. Four different harvest dates were adopted (30, 45, 60 and 75 days after planting (DAP).

Results and conclusion
At early stages of development, the highest percentage of dry matter accumulation went to vegetative growth, and then to tubers in the successive harvests. The maximum tuber yield, tuber bulking rate and harvest index (36.17 t/ha, 4.23 gplant-1day-1 and 0.8) was recorded for Belete variety. Belete variety can give reasonable yield after 45 DAP. Guassa variety (having a PC of 0.92 at 75 DAP) was able to produce 92% of its yield at 75 DAP and its yield was comparable with the highest yielding variety (i.e. Belete). In such areas where erratic rainfall is expected, Guassa and Belete can be used as early varieties in potato production systems.

Key words: potato, dry matter accumulation, tuber yield, BR, harvest index and PC

INTRODUCTION

Assimilate allocation results from the interaction of climatic conditions, cultural practices and genotypic characteristics. It is the result of interdependent parameters such as growth and development, which are difficult to analyse separately in experiments. For example, lateral stem development is restricted by growth when there is a shortage of available carbohydrate, and tubers initiation will not occur if the conditions are not appropriate, despite sufficient availability of assimilates. Therefore, growth is limited by developmental processes (Kooman and Rabbinge, 1996).

Growth analysis is a mathematical expression of environmental effects on the growth and development of crop plants. These environmental factors with geno-

✉e-mail: kirkime@gmail.com

types also influence the source-sink relationship which determines crop yield (Wang et al., 1997). In growth analysis, two basic measurements are made. These are dry weight and leaf area, and a large number of parameters are derived from these measurements. Total crop dry matter is the spatial and temporal integration of all plant processes. The rate of dry matter accumulation varies throughout the life cycle of a crop. Dry matter and leaf area are sampled at intervals ranging from days to weeks to quantify the effects of environmental influence or to analyze genotypic differences between crop cultivars (Echarte et al., 2008). Dry matter partitioning is the end result of the flow of assimilates to the sink organs (Marcelis, 1996), in this case to the tubers.

Potato (*Solanum tuberosum L.*) is a crop with a high potential for food security in Ethiopia, especially for highlanders, who have to face low income of the households and land shortage. Factors proving this include high harvest index, yield, nutritional quality of its tuber, and greater adaptability. It has a short cropping cycle and is one of the most efficient crops in terms of converting natural resources, labour and capital into a high quality food. It produces more dry matter per hectare than the world's major cereals, more protein per unit area than any other crop except soybeans (Smith, 1984), and more food per unit of area/water than any other major crop, and it produces high yields.

Potato crop growth and tuber yield have been linked to the duration of the growth cycle, which depends on climate, cultivar, and crop management (Tekalign and Hammes, 2005; Geremew et al., 2007). Therefore, to increase the amount of photosynthate translocated to the tuber, it is necessary to modify the environment so that the plants are more efficient in utilizing low sunlight. Assimilate in potato is partitioned between leaves, roots, shoots and tubers. The ratio of tuber dry matter to total dry matter is referred to as harvest index. The harvest index values at the end of the growing season vary from 61 to 91% (Allen and Scott, 1980). Potato harvest index is strongly correlated with net assimilation rate (Midmore and Prange, 1992) and the plant growth rate (Oktaviana et al., 2018). Harvest indices can also be expressed as partition coefficients (Tekalign and Hammes, 2005).

Dry matter production depends on the size of the leaf canopy, the rate at which the leaf functions (efficiency) and the time the canopy lasts (duration) (Belhu, 2003). There is a significant difference between potato varieties/cultivars with respect to dry matter production (Hammes and De Jager, 1990; Bisognin and Dellai, 2015). The commonly used growth analysis parameters are leaf area index (LAI), relative growth rate (RGR), net assimilation rate (NAR), and crop growth rate (CGR) (Gardner at al., 1985). LAI is one of the best predictors of plant growth and yield and has a direct effect on different physiological processes such as the solar radiation intercepted by plants (Villa et al., 2017).

The growth of different potato varieties has been extensively studied worldwide (Allen and Scott, 1980; Victorio et al., 1986; Geremew et al., 2007), and several models are available to describe or predict the total biomass when environmental parameters are known (Kooman and Rabbinge, 1996). Relative growth rate has a strong influence on assimilate allocation. The variation in assimilate allocation in potato depends on the weight of the tubers, which is a result of their time of initiation and relative growth rate (Kooman and Rabbinge, 1996). Understanding the pattern of assimilate partitioning is important for determining the potential yield of different potato varieties, and for designing strategies to increase tuber yield in the hot tropics where tuberization is poor (Tekalign and Hammes, 2005). Tuber yield of sweet potato is strongly correlated with net assimilation rate, leaf area index, crop growth rate and total dry weight (Soplanit et al., 2018).

Potato varieties/cultivars show differences with respect to assimilate partitioning rate, tuber yield, tuber quality, dry matter content and nutrient composition. This variability is useful for the selection of varieties/cultivars characterized by high rates of net photosynthesis, suitable for processing or table consumption, and cultivars with reduced rates of transpiration, better adapted to moisture-limited areas (Tekalign and Hammes, 2005).

Dry matter production and assimilate allocation rate of commonly grown potato varieties in Ethiopia were not studied and understood, which is essential for optimizing production packages. Therefore, this research was set up with the aim of evaluating the growth performance, dry matter partition coefficient and harvest index of widely grown potato varieties in Ethiopia.

MATERIALS AND METHODS

Description of the study area

The research was conducted at the Adet Agricultural Research Center (AARC) research site during the 2019/2020 and 2020/2021 cropping seasons. AARC is located in West Gojjam zone of Amhara regional state, North West Ethiopia. It is located at a longitude of 370 28' 38''E and latitude of 110 16' 16''N, and at an altitude of 2240 meters above sea level. The mean annual rainfall and maximum and minimum temperatures are 1250 mm, 34°C and 24°C, respectively. The research site had clay soil texture and the following mean physicochemical characteristics: bulk density (2.65 $g \cdot cm^{-3}$), soil porosity (21.13%), soil water holding capacity (22.93%), pH (5.47), P (8.607 ppm), N (0.191%), K (14.55 ppm) and OC (1.45%).

Experimental materials and management practices

Six potato varieties, namely Shenkola, Belete, Gudenie, Guassa, Dagim and Ater Ababa, were selected due to their different morphological growth characteristics. Randomized complete block design (RCBD) with three replications was used. A gross plot size of 3.75 m x 3.5 m was used. Row spacing of 75 cm, between plants of 35 cm and 1 m between replications and plots were used. Five rows/plot and ten plants/row were planted. All recommended agronomic practices were applied uniformly to all varieties. All plants in each plot were harvested for dry biomass measurement (at 90 DAP) to calculate the harvest index when they reached their maximum growth (when the ground was fully covered by the plants). Hence, this experiment had two replicates side by side, with one set left to maturity for agronomic data measurement and the other set harvested at maximum leaf development stage.

Data collected and analyses

Tuber yield was recorded from three middle rows of each plot and converted to a hectare basis. Immediately after 30, 45, 60, and 75 days after planting, three randomly selected plants were harvested from each treatment. The samples were separated into roots/tubers, stems and leaves, and dried to constant weight in an oven (70°C) for both 24 and 48 hours. Dry matter (%) for leaves, stems, roots and tubers was calculated by the formula given by Howlader et al. (2016):

$$= \frac{\text{leaf/ stem/ root/ tuber dry weight (g)}}{\text{Total dry weight of the plant (g)}} \text{ x } 100$$

At each harvest, green leaf area was measured by an electronic planimeter LiCor-3000. Leaf area indexes, specific leaf weight, crop growth rate, tuber growth rate, partition coefficient analysis were made at each harvest using the following formula:-

$$LAI = [(LA2 + LA1)/2] * (1/GA) \text{ (Gardner et al., 1985)}$$

$$SLW = (LW2/LA2 + LW1/LA1)/2 \text{ (Gardner et al., 1985)}$$

$$CGR = 1/GA * (W2 - W1)/ (t2 - t1) \text{ (Gardner et al., 1985)}$$

$$TGR = 1/GA * (T2 - T1)/ (t2 - t1) \text{ (Manrique, 1989)}$$

$$PC = TGR / CGR \text{ (Duncan et al., 1978)}$$

Where:
LAI is leaf area index; LA2 and LA1 are leaf area at time 2 (t2) and time 1 (t1), respectively; GA ground area covered by the crop; SLW is specific leaf weight expressed in $g \cdot cm^{-2}$, LW2 and LW1 are leaf dry mass at time 2 (t2) and time 1 (t1), respectively; CGR is crop growth rate expressed in $g \cdot m^{-2} \cdot day^{-1}$, W2 and W1 are total crop dry mass (g) at t2 and t1; TGR is tuber growth rate expressed in $g \cdot m^{-2} \cdot day^{-1}$; T2 and T1 are tuber dry mass (g) at t2 and t1; PC is partition coefficient.

$$\text{Bulking Rate (BR)} = \frac{\text{Wt of fresh root yld at harvest}}{\text{Period of root growth (Days)}}$$

(Allen and Scott, 1980).

A harvest index (HI) for each variety was calculated by the formula given by Frezgi (2007):-

$$HI = \frac{\text{Dry mass of Economic yield}}{\text{Dry mass of Biological yield}}$$

All data collected were checked for ANOVA Assumptions and subjected to analysis of variance using SAS Version 9.2 statistical software (SAS, 2008). Data from the two years were analysed together to confirm the homogeneity of error variances of the interaction of the year and treatment. Significant treatment means were compared using least significance difference (LSD) value at the 5% significance level (Montgomery, 2005).

RESULTS

Dry Masses

Stem dry mass (SDM) at 30 DAP, root dry mass (RDM) at all DAP, and tuber dry mass (TDM) at 30 and 45 DAP were not significantly different between varieties. But all the other leaf, stem, root, tuber and total dry masses were highly significantly and significantly ($P < 0.01$ and $P < 0.05$, respectively) varied between days after planting as well as between potato varieties (Table 1–4). Total dry weight varied significantly ($P < 0.05$) between tested cultivars. The highest total dry weight (135.76 g/plant) of potato was recorded from the variety Shenkola followed by Belete (131.33 g/plant) at 90 DAP (Table 13). Shenkola variety had lower yield when compared to the highest yielding Belete variety.

Leaf Dry Mass

With the exception of Guassa and Ater Ababa varieties, which had maximum LDM at 60 DAP, all varieties had maximum LDM at 75 DAP. The minimum LDM was recorded at 30 DAP in all varieties (Table 1). The maximum LDM (190 g/plant) was recorded in Gudenie and Belete varieties. The minimum (10 g/plant) was recorded in Dagim variety.

Stem Dry Mass

With the exception of Guassa and Ater Ababa varieties, all varieties had maximum SDM at 75 DAP. In all other varieties, the minimum SDM was recorded at 30 DAP (Table 2). The maximum SDM was recorded in Guassa variety (130.33 g/plant) at 60 DAP, while the minimum was in Shenkola, Belete and Dagim varieties at 30 DAP (Table 8).

Tuber Dry Mass and Root Dry Mass

With the exception of Guassa and Ater Ababa varieties, which had maximum TDM at 60 DAP, all varieties had maximum TDM at 75 DAP. The maximum (465 g/plant) TDM was recorded at 75 DAP. In all varieties, the minimum TDM (0 g/plant) was recorded at 30 DAP (Table 3). The maximum (465 g/plant) value at 75 DAP and minimum (0 g/plant) value at 30 DAP DM were recorded in Gudenie variety and in all varieties, respectively (Table 10). RDM increased to 60 DAP, then decreased in all varieties. The maximum RDM (565 g/plant) was recorded at 60 DAP and the minimum (1 g/plant) at 30 DAP. The maximum RDM was recorded in Gudenie variety (565 g/plant) and the minimum was in Belete and Dagim varieties (1 g/plant) (Table 4).

Table 1. Leaf dry mass (g/plant) of potato varieties at different days after planting (DAP) grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

	Variety					
DAP	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	15^{d}	20.33^{d}	21^{d}	40^{d}	10^{d}	15^{c}
45	70^{c}	50.33^{c}	80^{c}	65^{b}	40^{c}	40^{a}
60	75^{b}	160^{b}	105^{b}	160^{a}	45^{b}	25^{b}
75	80^{a}	190^{a}	190^{a}	60^{c}	100^{a}	10^{d}
Mean	60.08	105.17	99.08	81.25	48.75	22.5
LSD	4.54	5.21	2.72	1.99	2.31	2.31
CV (%)	4.02	2.03	1.45	1.23	2.37	2.36

Means with the same letter are not significantly different.

Table 2. Stem dry mass (g/plant) of potato varieties at different days after planting (DAP) grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

			Variety			
DAP	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	1.33[d]	1[d]	5[d]	30[d]	1.67[d]	1[d]
45	25[c]	55[c]	45[c]	35[c]	15[c]	10[c]
60	55[b]	90[b]	65[b]	130.33[a]	25[b]	30[a]
75	79.67[a]	135[a]	185[a]	55[b]	100[a]	20[b]
Mean	40.25	70.25	75.0	87.67	35.42	15.25
LSD	4.68	5.73	1.88	1.76	0.58	1.75
CV (%)	6.17	4.33	1.33	1.01	1.82	0.81

Means with the same letters are not significantly different.

Table 3. Tuber dry mass (g/plant) of potato varieties at different days after planting (DAP) grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

			Variety			
DAP	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	0[d]	0[d]	0[d]	0[d]	0[d]	0[d]
45	10[c]	10[c]	70[c]	30[c]	10[c]	5[c]
60	85[b]	295[b]	145[b]	180[a]	85[b]	95[a]
75	170[a]	350[a]	465[a]	175[b]	95[a]	85[c]
Mean	66.25	163.75	170.0	96.33	47.5	46.25
LSD	1.33	1.63	1.91	1.73	1.01	1.99
CV (%)	1.07	1.53	1.51	1.89	1.05	1.05

Means with the same letters are not significantly different.

Table 4. Root dry mass (g/plant) of potato varieties at different days after planting (DAP) grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

			Variety			
DAP	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	5[d]	1.33[d]	5[d]	5[d]	1[d]	5[d]
45	25[c]	25[c]	80[c]	70[c]	20[c]	20[c]
60	185[a]	400[a]	160[b]	290[a]	175[a]	165[a]
75	100[b]	375[b]	463[a]	200[b]	105[b]	95[b]
Mean	78.75	200.33	168.83	141.25	75.25	71.25
LSD	1.88	2.71	11.77	2.31	1.91	1.99
CV (%)	1.27	1.72	7.81	1.87	1.27	1.27

Means with the same letters are not significantly different.

Percentage of dry matter partitioned

In the early stages, all varieties had the highest mean percentage of dry matter partitioned to the leaves. Belete (90.9%) followed by Dagim (83.34%) had the highest dry matter partitioned to the leaves at early stages. At 75 DAP, Ater Ababa variety had the lowest (8.01%) dry matter partitioned to the leaves. Variety Guassa was in the middle in this regard, with 53.33% of assimilates partitioned to the leaves at 30 DAP. At 75 DAP, Guassa variety still constituted 19.04% of the dry mass partitioned to the leaves (Table 5). This study indicated that the most of the assimilates were partitioned to the leaves at an earlier stage of growth.

At 30 DAP, variety Guassa partitioned a larger (40.00%) fraction of assimilates to the stems. In the early stage of development, Ater Ababa and Belete variety can transfer (4.76% and 4.55%, respectively) fraction of assimilates to the stems. At 75 DAP, Belete and Shenkola varieties diverted the smallest (13.74%) and the largest (19.77%) proportion of assimilates to the stem growth, respectively (Table 5).

At 45 and 60 DAP, Ater Ababa variety transferred the largest (20.84% and 57.22%) fraction of assimilates to tubers. At 75 DAP, in all varieties transferred the largest fraction of assimilates to the roots and tubers. Ater Ababa variety followed by Guassa variety transferred the largest (58.73% and 55.56%) fraction of assimilates to tubers at 75 DAP (Table 5).

LAI, SLW, CGR, and TGR

Leaf area index (LAI)

LAI was highly significantly ($P < 0.01$) varied both between potato cultivars and between harvest days. Regardless of the variety, LAI increased progressively with time, reaching a peak at 60 DAP and decreasing thereafter. The maximum LAI (10.05) was recorded in Belete variety at 60 DAP and the minimum (0.23) in Dagim variety at 30 DAP (Figure. 1).

Table 5. Mean percentage (%) of dry matter partition to different organs for six potato varieties at different days after planting (DAP) grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

DAP	Leaves						Stems					
	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	71.43	90.9	66.66	53.33	83.34	71.43	4.76	4.55	16.77	40.00	8.33	4.76
45	58.33	38.46	42.00	38.24	53.33	57.14	20.83	42.31	26.00	20.58	20.00	14.29
60	23.81	23.02	20.21	23.53	26.67	14.36	17.46	19.42	19.68	33.82	26.67	16.64
75	30.77	29.01	16.33	19.04	25.71	8.01	30.77	13.74	18.36	17.46	14.29	15.97
Mean	46.09	45.35	36.3	33.54	47.26	36.99	18.46	20.01	20.20	27.97	17.32	12.17

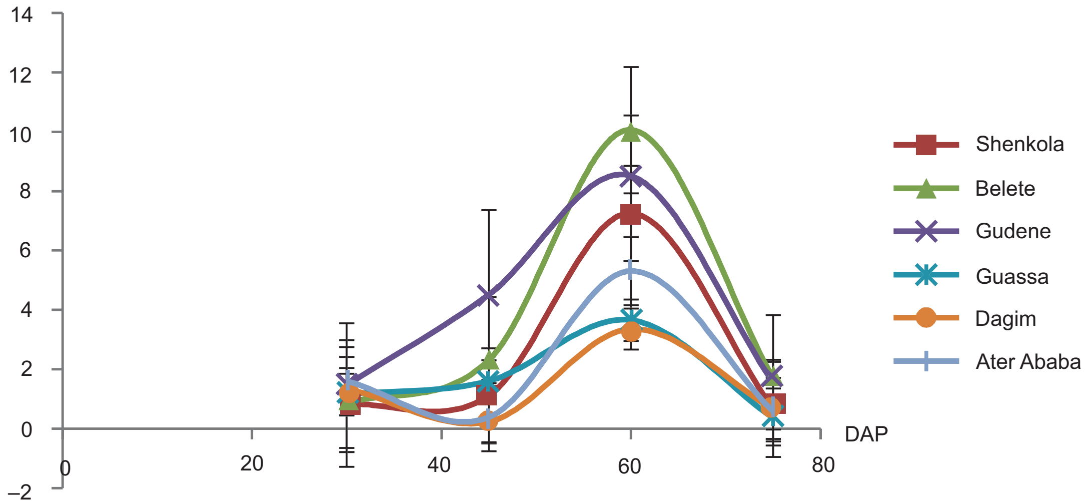
DAP	Roots						Tubers					
	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	23.81	4.55	16.67	6.67	8.33	23.81	0	0	0	0	0	0
45	20.84	19.23	32.00	41.18	26.67	28.57	8.34	7.69	18.00	17.65	13.33	20.84
60	58.73	57.25	50.11	42.65	46.67	69.00	42.63	42.45	41.18	46.47	22.67	57.22
75	38.46	57.56	65.31	63.5	60.00	76.02	53.97	43.43	49.47	55.56	34.29	58.73
Mean	35.46	34.65	43.52	38.5	35.42	50.85	26. 24	23.39	27.16	29.92	17.57	34.95

Are not statically analysed.

Specific leaf weight (SLW)
SLW varied highly significantly (P < 0.01) both between potato varieties and between days after harvest (Figure 2). SLW varied from 1.4 g · cm^{-2} (in Ater Ababa variety at 30 DAP) to 4.2 g · cm^{-2} in Gudenie variety at 45 DAP.

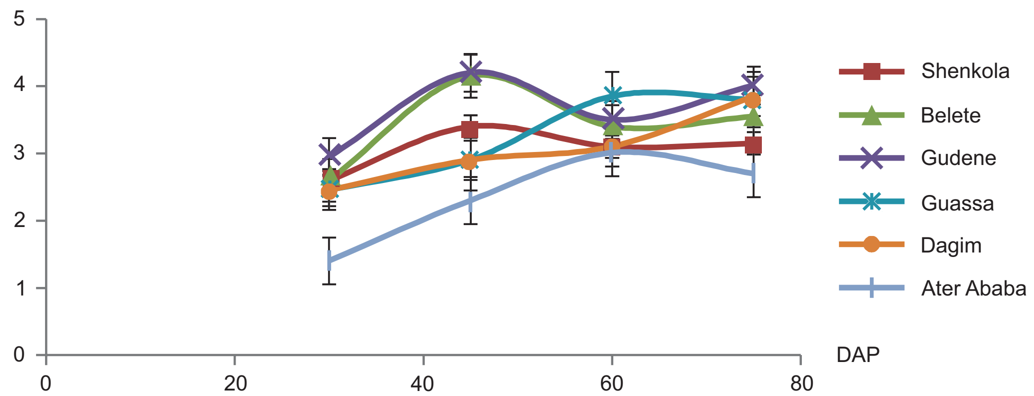
Crop growth rate (CGR)
CGR varied highly significantly (P < 0.01) both between potato varieties and between harvest days. Numerically, CGR ranged from 0.27 g · m^{-2} · day^{-1} to 0.49 g · m^{-2} · day^{-1} (Ater Ababa and Dagim varieties, respectively at 75 DAP) to 19.58 g · m^{-2} · day^{-1} (Belete variety at 75 DAP) (Figure 3).

Tuber growth rate (TGR)
TGR varied highly significantly (P < 0.01) both between potato varieties and between harvest days. TGR ranged from 0.23 g · m^{-2} · day^{-1} (in variety Dagim at 75 DAP) to 14.1 g · m^{-2} · day^{-1} (in Belete variety at 60 DAP). Up to 60 DAP, TGR increased in all varieties (Figure 4).



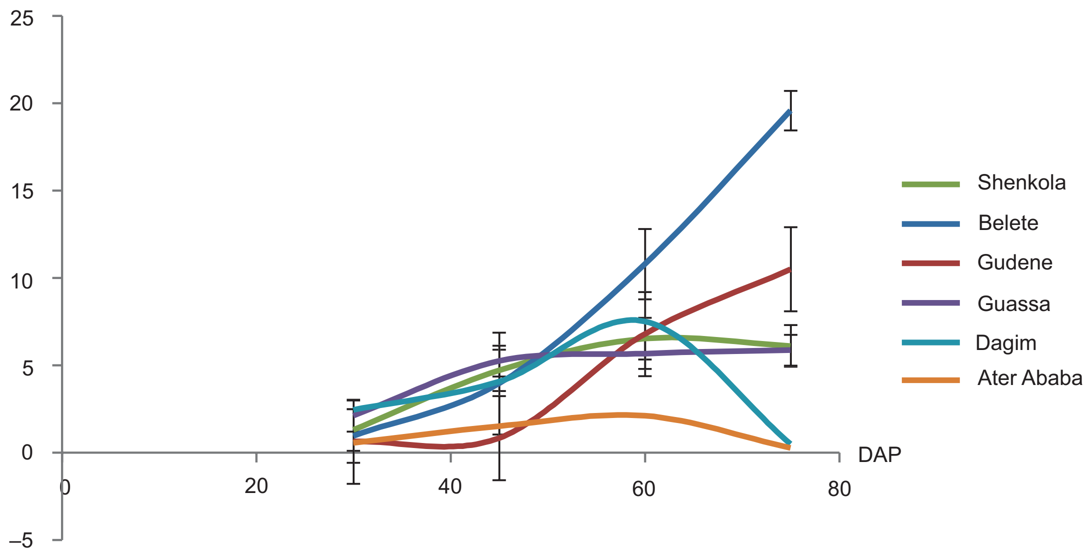
DAP = days after planting

Fig. 1. LAI of potato varieties at various harvest days grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons. Vertical bars represent standard error (source: own research)



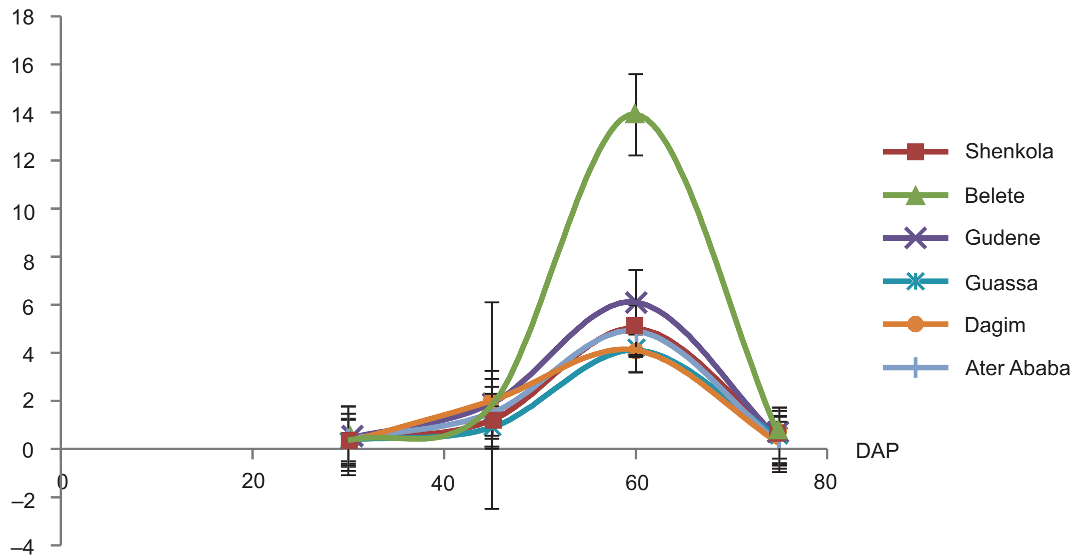
DAP = days after planting

Fig. 2. Specific Leaf Weight (SLW) of potato varieties at various harvest days grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons. Vertical bars represent standard error (source: own research)



DAP = days after planting

Fig. 3. CGR of potato varieties at various harvest days grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons. Vertical bars represent standard error (source: own research)



DAP = days after planting

Fig. 4. Tuber Growth Rate (TGR) of potato varieties at various harvest days grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons. Vertical bars represent standard error (source: own research)

Partition Coefficient (PC)
PC varied significantly ($P < 0.05$) both between potato varieties and between harvest days. An increasing trend in their PC values was observed in the tested varieties. It ranged from 0.14 (in Belete variety at 30 DAP) to 0.96 (in the Ater Ababa variety at 75 DAP). Ater Ababa varietyand Guassa variety can deliver up to 96% and 92%, respectively, of tuber yield at 75 DAP. At the end of 75 DAP, Belete variety can give only 65% of its total yield (Table 6).

Tuber yield, total dry matter, bulking rate and harvest index
A significant ($P < 0.05$) difference was recorded between potato varieties for tuber yield, number of marketable tubers, bulking rate and harvest index (HI) (Table 14). The maximum tuber yield (36.17 t/ha) was recorded in Belete variety, which was followed by Gudenie (27.90 t/ha) and Guassa varieties (27.71 t/ha). Tuber bulking rate was the highest in Belete variety (4.23 g/plant/day), followed by Shenkola (3.89 g/plant/day) and Guassa (3.89 g/plant/day) varieties. The lowest (0.7 g/plant/day) was recorded for Ater Ababa variety. The HI ranged from 0.84 (Belete variety) to 0.6 (Ater Ababa variety) (Table 7).

DISCUSSIONS

Differences in dry matter partitioning among potato varieties at different stages of harvesting were reported by Tekalign and Hammes (2005) and Howlader et al. (2016). Howlader et al. (2016) and Birhanu et al. (2014) also reported significant differences in total dry weight and root dry weight in potato and sweet potato varieties at all harvest days. Howlader et al. (2016) also reported that the highest total dry matter (134.14 g/plant) was recorded in a potato variety at the end of 80 DAP. At early stages most of the dry matter was accumulated in the leaves of a potato (Howlader et al., 2016) and sweet potato (Enyi, 1977). These authors also reported that at maturity, leaf and stem dry weights decreased due to the translocation of assimilates from shoot/leaf to tuber/root at the later stages. In contrast to the above results, Geremew et al. (2007) reported that leaf dry mass (LDM) and tuber dry mass (TDM) did not vary significantly between different varieties at all harvest days. This may be due to the different growth treatments applied and varieties used.

Shenkola variety (the highest total dry weight recorded) had a lower yield when compared to the highest yielding Belete variety. This was reported by Soplanit et al. (2018) as wider leaves combined with stem morphology can improve total dry weight. In contrast, Hoque et al. (2010) reported that the highest dry matter content was recorded in a high-yielding variety at 90 DAPs. The maximum stem dry mass (SDM) was recorded in Guassa variety, while the minimum was observed in Shenkola, Belete, Dagim and Ater Ababa varieties at 30 DAP (Table 9). In the early maturing varieties (Ater Ababa and Guassa), SDM decreased after 60 DAP, according to Howlader et al. (2016). Enyi (1977) also shown that during the first stage of sweet

Table 6. Partition coefficient (PC) of potato varieties at different days after planting at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

DAP	Variety					
	Shenkola	Belete	Gudenie	Guassa	Dagim	Ater Ababa
30	0. 25[e]	0.14[d]	0.18[d]	0.17[c]	0.21[c]	0.31[d]
45	0. 25[c]	0.44[c]	0. 28[c]	0.17[c]	0.51[b]	0.32[c]
60	0.65[b]	0.52[b]	0.59[b]	0.88[b]	0.72[a]	0.65[b]
75	0.68[a]	0.65[a]	0.71[a]	0.92[a]	0.72[a]	0.96[a]
Mean	0.58	0.44	0.44	0.42	0.54	0.61
LSD	0.02	0.02	0.03	0.02	0.02	0.01
CV	2.01	2.29	3.01	2.4	2.23	1.47

Means of the same column sharing the same letters are not significantly different ($P < 0.05$)

Table 7. Tuber yield, total dry matter, bulking rate and harvest index of potato varieties grown at the research site of Adet ARC during the 2019/2020 and 2020/2021 main cropping seasons (source: own research)

Variety	Tyield (t/ha)	TDM (g/plant)	BR (g/plant/day)	HI
Shenkola	25.19^{c}	135.76^{a}	3.89^{ab}	0.71^{c}
Belete	36.17^{a}	131.33^{b}	4.23^{a}	0.84^{a}
Gudenie	27.90^{b}	127.19^{c}	3.61^{b}	0.75^{b}
Guassa	27.71^{b}	126.83^{c}	3.89^{ab}	0.73^{b}
Dagim	25.05^{c}	121.71^{d}	1.78^{c}	0.70^{c}
Ater Ababa	10.54^{d}	110. 23^{e}	0.7^{d}	0.60^{d}
Means	25.41	27. 27	3.03	0.72
LSD	1.15	1.06	2.43	0.022
CV (%)	13.89	13. 27	11.02	1.7

Where Tyield/ha = Marketable Tuber yield, TDM= Total dry mass and BR = Bulking rate. Means with the same letter are not significantly different

potato growth, shoot growth dominates and a large proportion of dry mass is diverted to shoots.

The minimum TDM was recorded at 30 DAP. This is an indication that the tuber dry matter production was related to the duration of its growth. Such a result was reported by Tekalign and Hammes (2005). Geremew et al. (2007) also recorded that dry matter accumulation in potato tubers gradually increased after 30 DAP. A significant difference in stolon (root + tuber) dry mass was reported among different potato varieties with different phosphorous application rates by Fernandes and Soratto (2012).

The sharp increase in LAI at 60 DAP could be due to the increased production of leaves and the rapid rate of leaf expansion. LAI decreased at the beginning of senescence as reported by Villa et al. (2017) and Bisognin and Dellai (2015). Silva and Pinto (2005) also noticed that LAI of 2.5 to 3 was optimal for maximum light interception in potato plants. According to Howlader et al. (2016), leaf area index has also great effect on tuber yield and final dried plant material. LAI increase is like crop growth rate (CGR), which is determined by the amount of solar radiation intercepted by plant leaves needed to achieve the optimum photosynthetic level. This was reported by Belhu (2003) in sweet potato. In the early stages, potato uses photoassimilates for vegetative growth, and development of the roots and aerial part, and after this stage photoassimilates are remobilized for the formation of tubers. This result was also reported by Silva et al. (2020). This means that CGR increases in the vegetative phase and begins to decrease in the generative phases. At maximum LAI, Soplanit et al. (2018) recorded a CGR of 106–133 $g \cdot m^{-2}$. Figure 3 did not follow any defined patterns of increasing or decreasing order. The increasing trend of CGR with age up to 75 and 55 DAP was also indicated by Tekalign and Hammes (2005), and Silva et al. (2020), respectively. The decreasing trend of CGR (Guassa and Ater Ababa varieties) during the growing season indicated that these varieties were early. Late maturing varieties (Shenkola, Gudenie and Dagim) maintained increasing CGR until the last stage of sample harvest, which showed their long growing cycle (Figure 3). Such an undefined pattern of SLW was also observed by Howlader and Hoque (2018), and Geremew (2007). These authors also reported significantly different growth stages and specific leaf area among potato varieties. Variation in tuber initiation among potato varieties was reported by Olivera (2000), as sink competition for nutrients and photosynthates between plant organs increases with tuberization. Olivera also suggested that sink strength affects both assimilate allocation and leaf longevity or earliness. Furthermore, he indicated that SLW was highly correlated with leaf dry biomass. SLW also varied according to the position of the leaf in the plant and the treatments applied. In all varieties root dry mass and TGR increased up to 60 DAP. TDM increased to 75 DAP in the late maturing varieties in contrast to the early maturing cultivars, in which TDM increased to 60 DAP. This may be due to the fact that the final stolon/tuber yield is determined by the relative sink strength of the tubers and the production and the translocation of assimilates from the source leaves as reported by Hastilestari et al. (2018).

Ater Ababa and Guassa varieties accumulate dry matter in tubers at an early stage of maturation. Guassa variety was also reported by Solomon et al. (2019) to require intermediate days to maturity (110–115) compared to released potato varieties. Kooman and Rabbinge (1996) indicated that tuber growth rate influences earliness more than leaf longevity and tuber initiation. According to Howlader et al. (2016), effective partitioning of dry matter into tubers (80.5%) occurs at 80 DAP. Silva and Pinto (2005) also observed that about 77.33% of dry matter was partitioned to tubers at 83 DAP. Praharaj et al. (2010) reported the large increment of tubers after their set was due to large partitioning of dry matter to tubers.

Guassa and Ater Ababa varieties can transfer much dry matter to their tubers at the end of 75 DAP. Analyzing the differences between different varieties with respect to dry matter allocation indicated that variety Belete allocated about 42.75% of the total dry matter to the shoots and 43.43% of the total dry mater to tubers at 75 DAPs. Even though this variety allocates less dry matter to tubers at 75 DAP, it can still give reasonable yield at this stage. The percentage of TDM increased from 0% (in all varieties at 30 DAP) to 58.73% in Ater Ababa variety at 60 DAP (Table 3), which can be described by S-shaped curve. Barghi et al. (2012) reported that the varieties with the highest tuber dry mass at early stages were Guassa and Belete varieties, at 75 DAP. In areas where erratic rainfall is expected, meaning that potato is an ideal crop for production there, Aragaw et al. (2023), Guassa and Belete varieties can be used for production. Dagim variety was severely affected by late blight disease, resulting in the lowest TDM, LAI, CGR TGR at 75 DAP, and low yield. Marcelis (1996) reported that dry matter partitioning in the whole plant depends on the sink strength.

Geremew et al. (2007) identified three types of potato varieties: those cultivars in which tuber filling started early and harvest index increased rapidly with time; those cultivars in which tuber filling started early, but harvest index increased less rapidly with time; and those in which tuber filling started later and harvest index increased gradually with a continuous diversion of a major fraction of current assimilates to the production of new leaves and stem growth. Guassa and Ater Ababa varieties can be included in the first group, Belete in the second group, and Shenkola, Gudene and Dagim varieties in the third group.

Significant differences in tuber yield, bulking rate and harvest index (HI) between potato varieties were reported by Solomon et al. (2019). Genotypic bulking rate variability was studied by Mihovilovich et al. (2014). Varietal difference on the growth potential of potato varieties in Ethiopia was recorded by Tekalign and Hammes (2005) and Solomon et al. (2019). Howlader et al. (2016) observed the significant difference in yield among four potato genotypes. Olivera (2000) and Hoque et al. (2010) also reported different tuber yield potentials among different cultivars of potato. Genotypic variability of HI among Solanum species was reported by Victorio et al. (1986), Getachew et al. (2016) and Bélanger et al. (2001). Lahlou et al. (2003) also discovered a significant difference in HI ranging from 0.792 to 0.836 between different potato varieties grown under drought stress. The early tuber initiation in the Ater Ababa variety may have been detrimental to the yield performance of this variety. This was reported by Olivera (2000), as earliness is an adverse trait for tuber yield. On the other hand, a non-significant in HI difference was recorded by Mohammed et al. (2017). This was due to the fact that there were differences in variety, planting date and growth environment.

CONCLUSIONS

Total growth and tuber dry matter production of a potato are mainly determined by the growth period. These six potato genotypes differed significantly in all parameters evaluated for growth, partition coefficient and harvest indices. The results showed that except for stem dry mass at 30 DAP, root dry mass at all DAP, and tuber dry mass at 30 and 45 DAP parameters, all the other parameters varied highly significantly and significantly both between days after planting and between potato varieties. Except for Guassa and Ater Ababa varieties, which had maximum LDM and SDM at 60 DAP, all varieties had maximum LDM, SDM and TDM at 75 DAP. For all varieties, the maximum RDM was recorded at 60 DAP. At the early stages of development, the highest percentage of dry matter accumulation went to vegetative growth, and then to tubers in the successive harvests. LAI, SLW, CGR and TGR varied highly significantly both between potato varieties and between harvest days. Total dry mass, tuber yield, bulking rate, number of marketable tubers, harvest indexes and partition coefficients were significantly different between varieties and days after planting. The highest bulking rate, tuber yield and harvest indexes were recorded in Belete variety. The tuber filling started early in this cultivar, but harvest index increased less rapidly, so it can give reasonable yield at any stage of its growth. However, Guassa variety (having a PC of 0.92 at 75 DAP) was also able to produce 92% of its yield at 75 DAP and its yield was comparable with the highest yielding variety (Belete). In such areas where unpredictable rainfall is expected and potato is an ideal crop for production, Guassa and Belete varieties can be used as early varieties in potato production areas. All existing and newly released potato varieties should also be evaluated for growth, partition coefficient and harvest indices.

ACKNOWLEDGMENTS

The authors are very grateful to the Ministry of Education (Ethiopia) for sponsoring the doctoral program and providing funds needed for this study. The authors also are very grateful to the staff of the Adet Agricultural Research Center and the Amhara Region Agricultural Research Institute, who have been instrumental during field work and analysis.

REFERENCES

Allen, J.E., Scott, K.R. (1980). An Analysis of growth of the potato crop. J. Agric. Sci., Gamb., 94, 583–606.

Aragaw, M, Abebe, A., Worku, W., Amare, T. (2023). Assessment of farmers' perceptions concerning potato farming systems in North Western Ethiopia. Acta Sci. Pol. Formatio Circumiectus, 22 (1), 35–63. DOI: 10.15576/ASP.FC/2023.22.1.35

Barghi, A., Tobeh, A., Hassenzadeh, N. (2012). Effect of nitrogen fertilizer levels on tuber filling rate and protein assimilation in early and late maturing potato. Annals of Biological Research, 3 (9), 4264–4275.

Belhu, T. (2003). Agronomical and physiological factors affecting growth, development and yield of sweet potato in Ethiopia. Submitted in partial fulfillment of the requirements of Doctor of Philosophy Department of Plant Production and Soil Science In the Faculty of Natural and Agricultural Sciences. Pretoria.: University of Pretoria.

Bélanger, G., Walsh, J.R., Richards, J.E., Milbum, P.H., Ziadi, N. (2001). Tuber growth and biomass partitioning of two potato cultivars grown under different n fertilization rates with and without irrigation. American Journal of Potato Research, 78 (2), 109–117.

Birhanu, A. Fetien, A., Yemane, T. (2014). Evaluation of sweet potato (Ipomea batata L.) varieties for total storage root yield in south and south east zones of Tigray, Ethiopia. American Journal of Trade and Policy, 1, 3/ 3.

Bisognin, A.D., Dellai, J. (2015). Shoot growth restriction in dry matter partitioning and minituber production of potato plants. Ciência Rural, Santa Maria, 45, 11, 1917–1924.

Duncan, W.G., McClcud, E.D., McGraw, L.R. and Boote, J.K. (1978). Physiological aspects of peanut yield improvement. Crop Sci., 18, 1015–1020.

Echarte, L., Rothstein, S., Tollenaar, M. (2008). The response of leaf photosynthesis and dry matter accumulation to nitrogen supply in an older and a newer maize hybrid. Crop Sci., 48, 656–665. DOI: 10.2135/cropsci2007.06.0366

Enyi, C.A.B. (1977). Analysis of growth and tuber yield of sweet potato (*Ipomoea batatas*) cultivars. Journal of Agricultural Science, 88, 2, 421–430.

Fernandes, M.A., Soratto, P.R. (2012). Nutrition, dry matter accumulation and partitioning and phosphorus use efficiency of potato grown at different phosphorus levels in nutrient solution. R. Bras. Ci. Solo, 36, 1528–1537.

Gardner, F.P., Pearce, B.R., Mitchell, L.R. (1985). Growth and development. In: Physiology of Crop Plants, 187–208. Ames, IA: Iowa State Univ. Press

Geremew, E.B., Steyn, M.J., Annandale, G.J. (2007). Evaluation of growth performance and dry matter partitioning of four processing potato (Solanum tuberosum) cultivars. N. Z. J. Crop Hortic. Sci., 35, 385–393. DOI: 10.1080/01140670709510204

Getachew, A., Wassu, M., Tesfaye, A. (2016). Genetic Variability Studies in Potato (Solanum tuberosum L.) Genotypes in Bale Highlands, South Eastern Ethiopia. Journal of Biology, Agriculture and Healthcare, 6, 3.

Hammes, P.S., De Jager, J.A. (1990). Net photosynthetic rate of potato at high temperature. Potato Res. 33, 515–520.

Hastilestari, R.B., Lorenz, J., Hofmann, R.S., Pscheidt, D., Sonnewald, U. and Sonnewald, S. (2018). Deciphering source and sink responses of potato plants (Solanum tuberosum L.) to elevated temperatures. Plant Cell Environ., 41, 2600–2616.

Hoque, A.M., Miah, M.A.M., Hossain, S., Rahman, M.M. 2010. Profitability of Bari released Potato *(*Solanum tuberosum L.) varieties in some selected locations of Bangladesh. Bangladesh. J. Agril. Res., 37(1), 149–158.

Howlader, O., Hoque, A.M. (2018). Growth analysis and yield performance of four potato (Solanum tuberosum L.) varieties. Bangladesh Journal of Agricul, Res, 43 (2), 267–280.

Howlader, O., Hoque, A.M., Chowdhury, I.T. (2016). Dry Matter Partitioning in Four Potato Varieties. Journal of Crop Science and Technology, 6, 2.

Kooman, L.P., Rabbinge, R. (1996). An analysis of the relation between dry matter allocation to the tuber and earliness of a potato crop. Annals of Botany, 77, 235–242.

Lahlou, O., Ouattar, S., Ledent, F.J. (2003). The effect of drought and cultivar on growth parameters, yield and yield components of potato. Agronomie, EDP Sciences, 23 (3), 257–268. DOI:10.1051/agro:2002089. hal-00886178

Marcelis, M.F.L. (1996). Sink strength as a determinant of dry matter partitioning in the whole plant. Journal of Experimental Botany, 47, Special Issue,1281–1291.

Manrique, L.A. (1989). Estimation of tuber initiation in potatoes grown in tropical environments based on different methods of computing thermal time. American Potato Journal, 66, 7, 425–436.

Midmore, D.J., Prange, R.K. (1992). Growth responses of two Solanum species to contrasting temperatures and irradiance levels: Relations to photosynthesis, dark respiration and chlorophyll fluorescence. Annuals of Botany, 69, 13–20.

Mihovilovich, E., Carli, C., De Mendiburu, F., Hualla, V., Bonierbale, M. (2014). Tuber bulking maturity assessment of elite and advanced potato clones protocol. Lima (Peru): International Potato Center.

Mohammed, E.M., Watthier, M., Zanuncio, C.J., Santos, S.H. (2017). Dry matter accumulation and potato productivity with green manure. Idesia, 35, 1, 79–86.

Montgomery, D.C. (2005). Design and analysis of experiments, 97–203. 6th Edition. USA: John Wiley and Sons, Inc...

Oktaviana, T., Syarif, Z., Yanti, Y., Warnita, W. (2018). The growth and yield of potato (Solanum tuberosum L.) with application of indigenous Rhizobacterai and coumarin. International Journal of Agriculture and Research, 7, 1.

Olivera, S.A.C. (2000). Potato crop growth as affected by nitrogen and plant density potato crop growth as affected by nitrogen and plant density. Pesq. Agropec. Bras., 35, 5.

Praharaj, C.S., Govindakrishnan, M.P., and Lal, S.S. (2010). Dry matter distribution in potato genotypes as affected by physiological degree days. Potato J., 37(3– 4), 138–142.

SAS Institute. (2008). SAS/STAT User's Guide for personal computers Version 9. Cary, North Carolina, USA: SAS Inst.

Silva, D.C., Soares, P.E.M., Ferreira, H.M., Cavalcante, P.C.A., Andrade, V.A.G., Aquino, A.L. (2020). Dry matter and macronutrient extraction curves of potato varieties in the Alto Paranaíba region, Brazil. Rev. bras. eng. agríc. ambient, 24, 3.

Silva, L.A.S., Pinto, P.B.A.C. (2005). Duration of the growth cycle and the yield potential of potato genotypes. Crop Breed. Appli. Biotech., 5, 20-28.

Smith, M.A. (1984). Encyclopedia Americana. Danbury, Connecticut: Grolier Inc., Vol. 22.

Solomon, F., Asrat, A., Workie, A. (2019). Yield performance of potato (Solanum tuberosum L.) varieties under rainy season at Wogera District, North-Western Ethiopia. Journal of Academia and Industrial Research (JAIR), 7, 11.

Soplanit, A., Guritno, B., Ariffin A., Suminarti, E.N. (2018). Relationship between yield and growth of sweet potato (Ipomoea batatas L.) on abiotic stress in Papua highland, Indonesia: Adaptation of varieties and sticks inclination angles. Bioscience Research, 15(2), 762–771.

Tekalign, T., Hammes, P.S. (2005). Growth and biomass production in potato grown in the hot Tropics as influenced by paclobutrazol. Plant Growth Regul., 45, 37–46.

Victorio, G.R., Moreno, U., Black, C.C. (1986). Growth, partitioning, and harvest index of tuber-bearing solanum genotypes grown in two contrasting Peruvian environments. Journal of Plant Physiol., 82(1), 103–108.

Villa, M. P., Sarmiento, L., Rada, J.F., Machado, D., Rodrigues, C.A. (2017). Leaf area index of potato (*Solanum tuberosum* L.) crop under three nitrogen fertilization treatments. Agronomía Colombiana, 35(2), 171–175.

Wang, Z., Fu, J., He, M., Tian, Q., Cao, H. (1997). Effects of source/sink manipulation on net photosynthetic rate and photosynthate partitioning during grain filling in winter wheat. Biol Plantarum., 39 (3), 379–85.

Waring, R., Landsberg, J., Linder, S. (2016). Insights gained from light use and leaf growth efficiency indices. Forest Ecology and Management, 379, 232–242.

WYDAJNOŚĆ WZROSTU, WSPÓŁCZYNNIK PODZIAŁU I WSKAŹNIK ZBIORÓW POWSZECHNIE UPRAWIANYCH ODMIAN ZIEMNIAKA (*SOLANUM TUBEROSUM* L.) W ETIOPII

ABSTRAKT

Cel pracy

Głównym celem badań było porównanie różnic w wydajności wzrostu, współczynniku podziału suchej masy oraz wskaźniku zbiorów powszechnie uprawianych odmian ziemniaka.

Materiały i metody

Badania przeprowadzono w Centrum Badań Rolniczych w Adet w Etiopii podczas głównych sezonów uprawowych 2019/2020 i 2020/2021, przy użyciu randomizowanego kompletnego projektu blokowego dla odmian Shenkola, Belete, Gudenie, Guassa, Dagim i Ater Ababa Przyjęto cztery różne terminy zbiorów (30, 45, 60 i 75 dni po posadzeniu (DAP)).

Wyniki i wnioski

Na wczesnych etapach rozwoju najwyższy procent akumulacji suchej masy przypadał na wzrost wegetatywny, a następnie na bulwy w kolejnych zbiorach. Maksymalny plon bulw, wskaźnik pęcznienia bulw i indeks zbioru (36,17 t/ha, 4,23 g plant^{-1} dzień$^{-1}$ i 0,8) odnotowano dla odmiany Belete. Na wczesnych etapach rozwoju najwyższy procent akumulacji suchej masy przypadał na wzrost wegetatywny, a następnie na bulwy w kolejnych zbiorach. Maksymalny plon bulw, wskaźnik pęcznienia bulw i indeks zbioru (36,17 t/ha, 4,23 g plant^{-1} dzień$^{-1}$ i 0,8) odnotowano odpowiednio dla odmiany Belete. Odmiana Belete może dać umiarkowany plon po 45 DAP. Odmiana Guassa (o współczynniku podziału 0,92 w 75 DAP) była w stanie wyprodukować 92% swojego plonu w 75 DAP, a jej plon był porównywalny z najwyżej plonującą odmianą (tj. Belete). Na takich obszarach, gdzie spodziewane są nieregularne opady deszczu, Guassa i Belete mogą być stosowane jako wczesne odmiany w systemach produkcji ziemniaków.

Słowa kluczowe: ziemniak, akumulacja suchej masy, plon bulw, wskaźnik pęcznienia, wskaźnik zbiorów, wskaźnik podziału