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Scientia Horticulturae 105 (2005) 29–44
SCIENTIA HORTICULTURAE
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Growth and productivity of potato as influenced by cultivar and reproductive growth II. Growth analysis, tuber yield and quality

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Received 7 August 2004; received in revised form 4 January 2005; accepted 27 January 2005

Abstract

A field experiment was conducted under sub-humid tropical conditions in Ethiopia using determinate cultivars Al-624, Al-436, CIP-388453-3(A) and CIP-388453-3(B) to study the effect of flowering and berry set on the growth, tuber yield, and quality of potato. Three treatments, viz. debudded, flowering, and fruiting plants were compared and standard growth analysis techniques were applied to study the growth pattern. Fruiting plants exhibited reduced leaf area index, tuber growth rate, and partitioning coefficient, but had higher crop growth rates and net assimilation rates. Fruit development reduced total and marketable tuber mass and tuber number without affecting the unmarketable component. Cultivars varied with respect to tuber yield, tuber number, size distribution, specific gravity, dry matter content, and nutrient composition. Fruiting reduced tuber specific gravity and dry matter content while increasing P, K, Mg, Fe, and Mn content of the tubers. Reproductive growth did not affect tuber Ca, S, Cu, and Zn concentrations. The field experiment demonstrated that reproductive growth restricts vegetative growth and reduces tuber yield and dry matter content of potato.

Keywords: Berry set; Dry matter content; Growth analysis; Tuber quality; Tuber yield

1. Introduction

In most herbaceous annual plants, vegetative growth is terminated by reproductive growth. Developing flowers and fruit are stronger sinks for mineral nutrients, sugar and

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0304-4238/$ – see front matter
doi:10.1016/j.scienta.2005.01.021

amino acids, and there is a corresponding decrease in the amounts available for the growth of other plant parts (Salisbury and Ross, 1992). Studies in various crops showed that growing fruit are strong sinks and suppress the growth of vegetative organs (Cockshull et al., 1992; Eckstein et al., 1995; Letchamo and Gosselin, 1995; Heuvelink, 1997). There is evidence indicating that during the reproductive phase, leaves, stems, and other vegetative parts compete for assimilates with the developing fruit (Eckstein et al., 1995; Heuvelink, 1997; Famiani et al., 2000) and sometimes previously accumulated carbon and minerals are mobilized and redistributed (Gardner et al., 1985). The distribution of assimilates within the plant is primarily regulated by the sink strength of sink organs (Ho et al., 1989; Marcelis, 1996).

Dry weight accumulation is commonly used as parameter to characterize growth because it usually has a great economic significance. The total dry matter yield of crops depends on the size of leaf canopy, the rate at which the leaf functions (efficiency), and the length of time the canopy persists (duration). The production of assimilates by the leaves (source) and the extent to which they can be accumulated in the sink representing the organs that are harvested significantly influences crop yield (Hahn, 1977). Growth analysis has widely been used to study yield influencing factors and plant development as net photosynthate accumulation over time (Gardner et al., 1985). A study of the pattern of dry matter distribution among plant parts is important for the evaluation of the growth rate, productivity and the yield level of potato (Nganga, 1982).

Albeit their relationship is not well understood, shoot and tuber growth of potato are genetically considered as competing processes (Almekinders and Struik, 1996). The inflorescence as a sink in potato plants has not received adequate attention and growers view flowers and berries as a minor nuisance. Results with other root crops showed that reproductive growth restrict the development of underground storage organs such as sugar beet (Wood and Scott, 1975), onion (Khan and Asif, 1981) and Jerusalem artichoke (Rice et al., 1990). However, detail work has not been done regarding the effects of reproductive growth on potato tuber growth, and results are conflicting. So and so reported flower and berry set have depressing effect on tuber growth (ProundFoot, 1965; Jansky and Thompson, 1990). On the contrary, Haile-Micheal (1973) observed no consistent relationship between reproductive growth and tuber growth. A previous Ethiopian study on the effect of reproductive growth on vegetative growth and tuber yield of potato showed that reproductive growth restricted vegetative growth and reduced tuber yield and quality (Tsegaw and Zelleke, 2002). This finding called for a more detailed investigation of how reproductive growth affects growth, tuber yield, tuber quality and nutrient composition. Accordingly, this paper reports on the effect of reproductive growth on growth, yield, quality and nutrient composition of potato tubers.

2. Materials and methods

2.1. Area descriptions

The study was conducted during February–June 2003 on the research farm of Alemaya University, Ethiopia. The experimental site is located at 42°3′E longitude, 9°26′N latitude

and at an altitude of 1980 m a.s.l. It is situated in the semi-arid tropical belt of eastern Ethiopia and characterized by a sub-humid type of climate with average annual rainfall of about 790 mm, annual mean temperature of 17 °C with mean minimum and maximum temperature of 3.8 and 25 °C, respectively. During the study period the mean maximum temperature was 26 °C (range 20.5–29 °C) and minimum temperature 11.4 °C (range 7.8–16.4 °C). During the growing period a total of 177 mm precipitation was received and supplementary irrigation was applied. Mean sunshine hour was 9.7 per day along with a relative humidity of 41% (range 19–71%). The soil of the experimental site is a well-drained deep alluvial that contains 14 g kg^{-1} organic carbon, 1.4 g kg^{-1} total nitrogen, 0.007 g kg^{-1} available phosphorus, 0.47 g kg^{-1} total potassium, and a pH of 7.2.

2.2. Cultivars

To obtain a range of genotypes from comparatively light to profusely blooming types and from light to heavy fruit setting, cultivars having different floral and berry development behaviour were selected. The four determinate cultivars were CIP-388453-3(A), CIP-388453-3(B), Al-624, and Al-436.

2.3. General field procedure

Forty-nine medium sized and well-sprouted tubers of each cultivar were planted in seven rows of a sub-plot (size = 11.025 m^2) at a spacing of 75 cm × 30 cm. Sub plots within the main plots were arranged continuously and the end plots were bordered by two rows of potato plants. Phosphorus was applied as diammonium phosphate at planting time at a rate of 150 kg P ha^{-1} and nitrogen was side dressed after full emergence at a rate of 100 kg N ha^{-1} in the form of urea. All other cultural practices were applied according to the regional recommendation. No major disease and insect pest incidence encountered.

2.4. Treatments

The study was designed to grow plants by providing the following three different types of treatments:

(1) Non-flowering plants (debudded plants): flower clusters were nipped off at bud emergence stage at 2 days intervals.
(2) Flowering plants: the plants were permitted to flower but not to set fruit. The flowers were removed after anthesis. This process was repeated every 2 days.
(3) Fruiting plants (control): plants were allowed to flower and set berries.

2.5. Experimental design

The experimental plots were arranged in a split-plot design in a randomised complete block design replicated three times. The four cultivars were assigned to the main-plots and the three reproductive growth manipulation treatments to the sub-plots.

2.6. Data recorded

2.6.1. Growth analysis

Every 14 days three plants were sampled from each sub-plot and separated into leaves, stems, tubers, and roots and stolons. Green leaf area was measured with a portable CI-202 leaf area meter (CID Inc., Vancouver, Washington State, USA). Plant tissues were oven dried at 72 °C to a constant mass. The following standard growth analysis parameters were calculated:

- LAI $= [(L_{A2} + L_{A1})/2](1/G_A)$ (Gardner et al., 1985);
- SLW $= (L_{W2}/L_{A2} + L_{W1}/L_{A1})/2$ (Gardner et al., 1985);
- CGR $= 1/G_A(W_2 - W_1)/(t_2 - t_1)$ (Gardner et al., 1985);
- TGR $= 1/G_A(T_2 - T_1)/(t_2 - t_1)$ (Manrique, 1989);
- FGR $= 1/G_A(F_2 - F_1)/(t_2 - t_1)$;
- RGR $= ((\ln W_2 - \ln W_1)/(t_2 - t_1)) \times 1000$ (Gardner et al., 1985);
- NAR $= [(W_2 - W_1)/(t_2 - t_1)][(\ln L_{A2} - \ln L_{A1})/(L_{A2} - L_{A1})]$ (Gardner et al., 1985);
- PC $=$ TGR/CGR (Duncan et al., 1978).

where LAI is leaf area index, L_{A2} and L_{A1} are leaf area at time 2 (t_2) and time 1 (t_1), respectively, G_A ground area covered by the crop, SLW is specific leaf weight expressed in g cm^{-2}, L_{W2} and L_{W1} are leaf dry mass at time 2 (t_2) and time 1 (t_1), respectively, CGR is crop growth rate expressed in g m^{-2} day^{-1}, W_2 and W_1 are total crop dry mass (g) at t_2 and t_1, TGR is tuber growth rate expressed in g m^{-2} day^{-1}, T_2 and T_1 are tuber dry mass (g) at t_2 and t_1, FGR is fruit growth rate expressed in g m^{-2} day^{-1}, F_2 and F_1 are fruit dry mass (g) at t_2 and t_1, RGR is relative growth rate expressed in mg g^{-1} day^{-1}, NAR is net assimilation rate expressed in g m^{-2} day^{-1}, and PC is partitioning coefficient.

2.6.2. Tuber yield and yield components

Tubers fresh mass and tuber numbers represent the average of 15 plants per treatment (sub-plot). Tubers weighing less than 50 g were considered unmarketable.

2.6.3. Quality assessment

At harvest, a representative tuber sample from each sub-plot was taken and washed. Tuber specific gravity was determined by weighing in air and under water (Murphy and Goven, 1959). To determine dry matter content of the tubers the samples were chopped and dried at a temperature of 60 °C for 15 h and followed by 105 °C for 3 h. Tuber dry matter content is the ratio between dry and fresh mass expressed as a percentage.

Samples dried at 60 °C were analysed for total nitrogen (Macro–Kjeldahl method, AOAC, 1984), and tuber crude protein content was calculated by multiplying total nitrogen by a conversion factor of 6.25 (Van Gelder, 1981). Following wet-ash digestion, phosphorus was determined by colorimetry, potassium by flame photometer, sulphur by turbidimetry, and calcium, magnesium, iron, copper, manganese and zinc by atomic absorption.

2.6.4. Statistical analysis

The analyses of variance were carried out using MSTAT-C statistical software (MSTAT-C, 1991). Means were compared using least significant differences (LSDs) test at 5% probability level. Correlations between parameters were computed when applicable. Trends in different growth parameters were analysed by linear regression, using Microsoft Excel 2000.

3. Results

For most of the growth parameters considered there were no differences among the cultivars. Flowering and fruit set influenced most of the growth parameters. During the first harvest period (0–2 weeks), reproductive growth did not significantly influenced leaf area index (Fig. 1). However, during subsequent sampling periods debudded plants showed consistently higher leaf area indices than plants allowed to flower or set berries.

The relative growth rate (RGR) decreased linearly over the 8-week sampling period for all the three treatments (Fig. 2). During the first sampling period debudded plants exhibited higher RGR (21 mg g^{-1} day^{-1}) than flowering (19 mg g^{-1} day^{-1}) and fruiting (18 mg g^{-1} day^{-1}) plants. For the third sampling period, fruiting plants had a higher relative growth rate than other treatments, while during the second and fourth observation periods no differences occurred.

The net assimilation rate declined from about 3 g m^{-2} day^{-1} to nearly 1.6 g m^{-2} day^{-1} towards maturity (Fig. 3). During the first sampling period (0–2 weeks), debudded plants

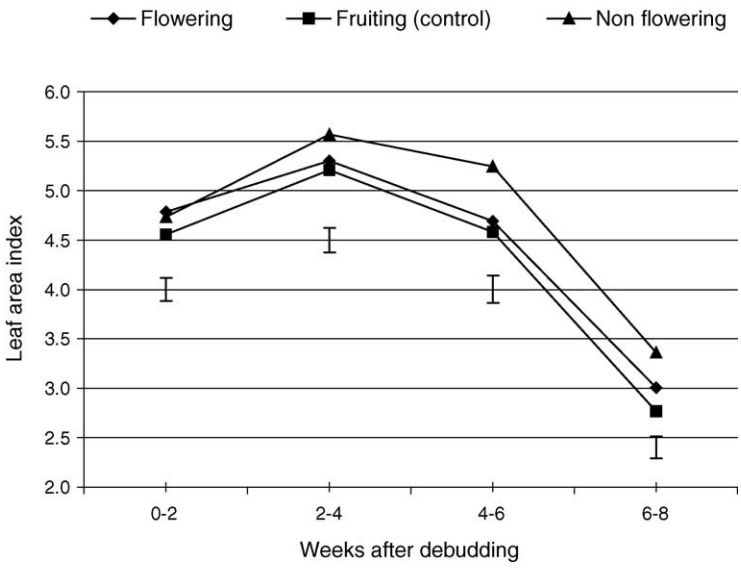

Fig. 1. The effect of flowering and berry set on leaf area index of potato. The vertical bars represent least significant differences at $P < 0.05$.

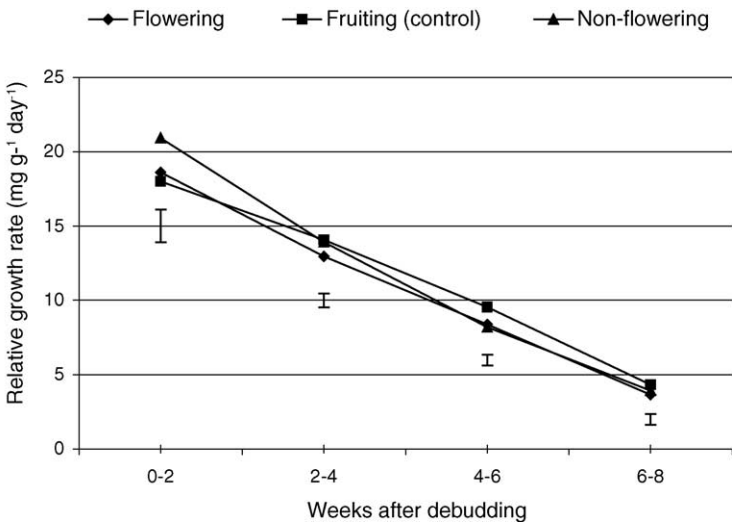

Fig. 2. Relative growth rate of potato as affected by flowering and berry set. The vertical bars represent least significant differences at $P < 0.05$.

had the highest net assimilation rate (3.2 g m^{-2} day^{-1}) and flowering plants the lowest (2.6 g m^{-2} day^{-1}). During the second sampling period, fruiting plants showed a higher net assimilation rate than flowering plants while the debudded plants were intermediate. During the subsequent samplings, fruiting plants exhibited a higher net assimilation rate than flowering and debudded plants.

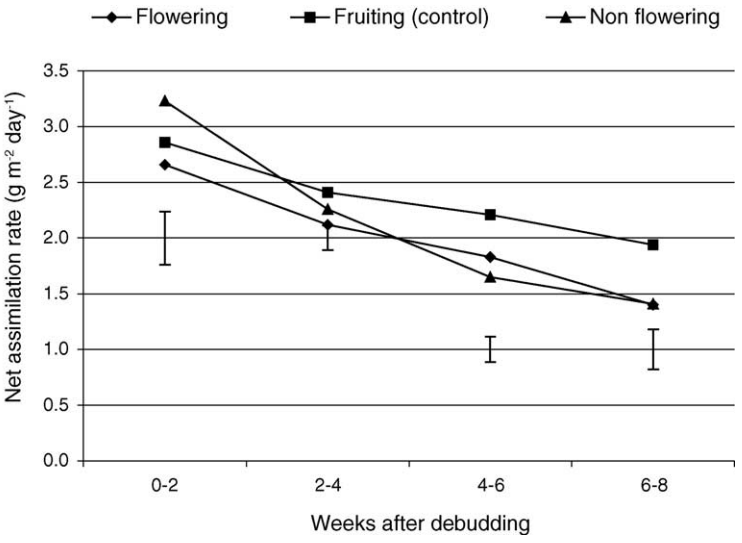

Fig. 3. Net assimilation rate of potato as affected by flower and berry production. The vertical bars represent least significant differences at $P < 0.05$.

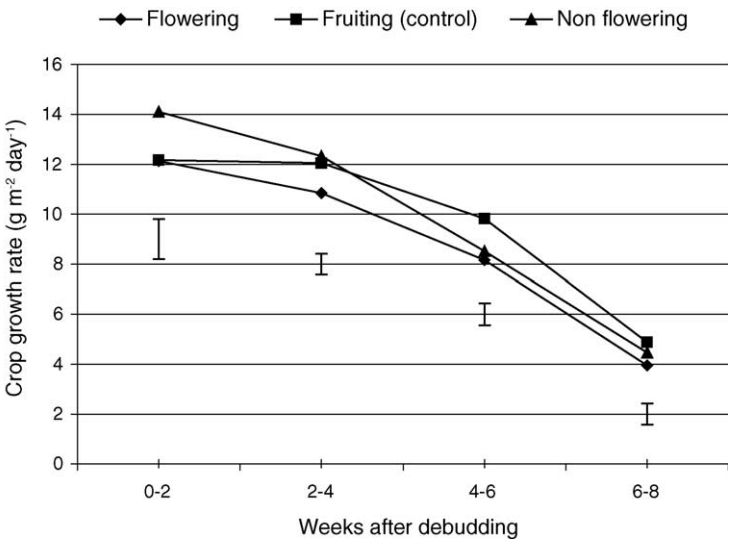

Fig. 4. The effect of flowering and berry set on potato crop growth rate. The vertical bars represent least significant differences at $P < 0.05$.

Crop growth rate declined sharply from over 12 g m^{-2} day^{-1} (during 0–2 weeks) to less than 5 g m^{-2} day^{-1}during the final sampling period (Fig. 4). From the time of debudding up to the second week, debudded plants exhibited a higher crop growth rate than flowering and fruiting plants. During the two to 4-week period, debudded and fruiting plants had higher crop growth rates. During the third sampling period fruiting plants showed higher crop growth rates than the other treatments. Towards maturity comparable crop growth rate of about 4.4 g m^{-2} day^{-1} was recorded for all three treatments.

Tuber growth rate and fruit growth rate (pooled over cultivars) are presented in Fig. 5. Peak tuber growth rate (5.7 g m^{-2} day^{-1}) was recorded 2–4 weeks after flower bud removal on the non-flowering plants and declined after wards. At all sampling periods, the debudded plants demonstrated higher tuber growth rate than fruiting plants and followed by the flowering plants. The fruit growth rate increased progressively from 1.14 g m^{-2} day^{-1} (0–2 weeks) to a peak of 1.70 g m^{-2} day^{-1} during the third sampling period (4–6 weeks), and declined sharply towards maturity.

The partitioning coefficient illustrated in Fig. 6 indicates the ratio of tuber growth rate to crop growth rate. Except for the second harvesting phase (2–4 weeks after debudding), fruiting plants exhibited a lower partitioning coefficient than non-flowering plants.

Cultivars differed greatly with respect to berry production potential. The rank of cultivars in decreasing order of fresh berry mass is Al-624 (275 g $hill^{-1}$), CIP-388453-3(B) (226 g $hill^{-1}$), Al-436 (209 g $hill^{-1}$), and CIP-388453-3(A) (81 g $hill^{-1}$). Cultivar Al-624 produced 26 berries per hill, followed by CIP-388453-3(B), Al-436, and CIP-388453-3(A) with respective mean berry numbers of 22, 19, and 14.

Differences between cultivars in total, marketable, and unmarketable tuber yield are presented in Table 1. Cultivar CIP-388453-3(A) produced the higher total tuber yield

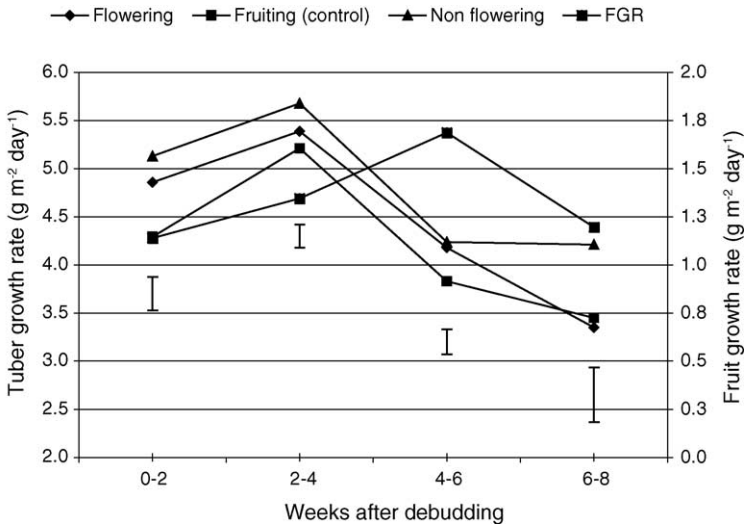

Fig. 5. Tuber growth rate as influenced by reproductive growth and fruit growth rate (FGR) of potato. The vertical bars represent least significant differences at $P < 0.05$ and use only for tuber growth rate comparison among treatments.

(991 g hill^{-1}), followed by Al-436 (849 g hill^{-1}), CIP-388453-3(B) (711 g hill^{-1}), and Al-624 (567 g hill^{-1}). Al-624 had a much smaller proportion of unmarketable (smaller tubers) than the other three cultivars. Cultivars CIP-388453-3(B), Al-436 and CIP-388453-3(A) produced a higher proportion of small tubers than Al-624. A significant difference was

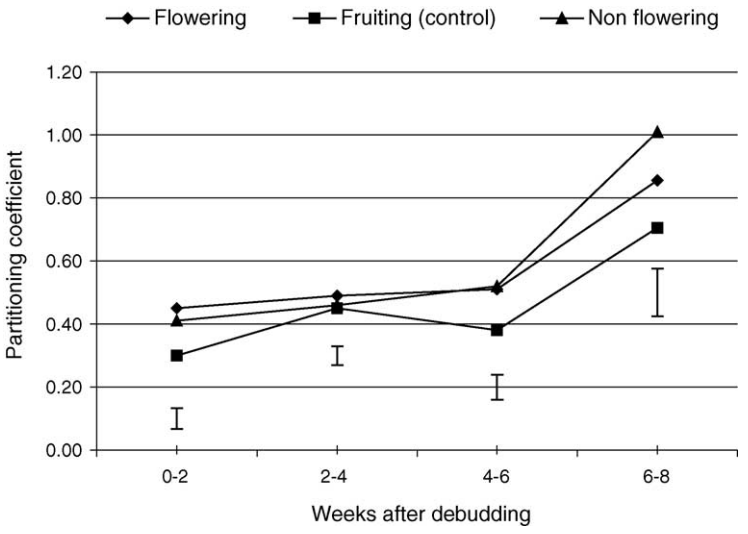

Fig. 6. Partitioning coefficient of potato as affected by flower and berry development. The vertical bars represent least significant differences at $P < 0.05$.

Table 1
Total, marketable and unmarketable tuber yield and number as influenced by cultivar and flowering and fruit set in potato

Main effect	Tuber yield (g hill^{-1})			Tuber number (count hill^{-1})		
	Total	Marketable	Unmarketable	Total	Marketable	Unmarketable
Cultivar						
CIP-388453-3(A)	991.0 a	837.3 a	153.7 a	11.6 b	6.4 a	5.2 b
A-624	566.7 d	517.6 c	49.1 b	5.4 c	3.5 b	1.9 c
Al-436	849.2 b	672.8 b	176.4 a	14.0 a	7.8 a	6.2 b
CIP-388453-3(B)	711.5 c	525.2 c	186.3 a	15.3 a	5.9 a,b	9.4 a
S.E.M.	21.52	15.64	10.78	0.45	0.22	0.52
Treatment						
Non-flowering	844.3 a	696.6 a	147.7 a	12.2 a	6.2 a	6.0 a
Flowering	822.9 a	678.4 a	144.5 a	11.8 a	6.2 a	5.6 a
Fruiting (control)	671.6 b	539.7 b	131.9 a	10.7 b	5.3 b	5.4 a
S.E.M.	14.92	13.91	6.20	0.16	0.23	0.24

S.E.M.: standard error of the mean. Means within the same main effect and column sharing the same letters are not significantly different ($P < 0.05$).

observed among cultivars with respect to total number of tubers (Table 1). CIP-388453-3(B) and A-436 produced a total of about 15 tubers, followed by CIP-388453-3(A) and Al-624 producing 12 and 5 tubers per hill, respectively. Fruit development decreased the productivity by reducing both tuber size and number. Without affecting the unmarketable component, fruit development reduced the total and marketable tuber yield by about 19 and 22%, respectively, as compared to the other two treatments. Similarly, without affecting the unmarketable component, fruit development decreased the total and marketable number of tubers than the other treatments.

The cultivars differed in tuber dry matter content as well as specific gravity (Table 2). CIP-388453-3(A) and CIP-388453-3(B) produced tubers containing approximately 22% dry matter which is higher than the tuber dry matter content of Al-436 and Al-624 (19%). Cultivars in decreasing order of tuber specific gravity are CIP-388453-3(A) (1.090 g cm^{-3}), CIP-388453-3(B) (1.085 g cm^{-3}), Al-436 (1.076 g cm^{-3}), and Al-624 (1.070 g cm^{-3}). The presence of berries reduced tuber dry matter content as well as specific gravity. Fruit development reduced tuber dry matter content by about 3.3% compared to flowering and non-flowering plants. Tubers of the non-flowering and flowering plants showed higher specific gravity (1.081 g cm^{-3}) than the fruiting ones (1.078 g cm^{-3}).

The cultivars differed with respect to tuber crude protein content and the concentration of macronutrients as indicated in Table 2. Al-624 produced tubers with a higher crude protein content (10%, on dry matter base), followed by Al-436 (7.4%), CIP-388453-3(B) (6.8%), and CIP-388453-3(A) (5.6%). Cultivar Al-624 also produced tubers with a higher phosphorus, potassium, calcium, sulphur, and magnesium content compared to the other cultivars. Interestingly, fruit development increased tuber crude protein content and phosphorus, potassium, and magnesium content without affecting calcium and sulphur (Table 2). Fruiting plants produced tubers containing higher crude protein, phosphorus and potassium content than tubers from the non-flowering and flowering treatments. The three

Table 2
The effect of cultivar and reproductive growth on dry matter content, specific gravity, crude protein content, and macroelement content of potato tubers

Main effect	Dry matter content (%)	Specific gravity (g cm^{-3})	Crude protein (%)	P (%)	K (%)	Ca (%)	S (%)	Mg (%)
Cultivar								
CIP-388453-3(A)	22.8 a	1.090 a	5.6 d	0.26 b	2.25 c	0.060 b	0.08 d	0.132 b
A-624	18.6 b	1.070 b	10.1 a	0.34 a	3.00 a	0.072 a	0.50 a	0.159 a
Al-436	19.8 b	1.076 a,b	7.4 b	0.26 b	2.42 b	0.054 b	0.15 c	0.132 b
CIP-388453-3(B)	21.8 a	1.085 a,b	6.8 c	0.28 a,b	2.27 c	0.059 b	0.22 b	0.128 b
S.E.M.	0.39	0.002	0.04	0.002	0.02	0.002	0.007	0.001
Treatment								
Non-flowering	21.0 a	1.081 a	7.4 b	0.28 b	2.44 b	0.060 a	0.22 a	0.136 b
Flowering	20.9 a	1.081 a	7.3 b	0.28 b	2.47 b	0.063 a	0.25 a	0.137 b
Fruiting (control)	20.3 b	1.078 b	7.8 a	0.29 a	2.53 a	0.061 a	0.24 a	0.141 a
S.E.M.	0.11	0.001	0.03	0.001	0.007	0.001	0.12	0.001

S.E.M.: standard error of the mean. Means within the same min effect and column sharing the same letters are not significantly different ($P < 0.05$).

treatments had comparable tuber calcium (0.06%), sulphur (0.24%), and magnesium (0.14%) contents.

Cultivars exhibited distinction with respect to tuber copper and zinc concentration while having comparable iron and manganese contents (Table 3). The mean copper content of the tubers were 20 ppm for Al-624, CIP-388453-3(A) and CIP-388453-3(B) which is higher than in the case of cultivar Al-436 (18 ppm). Cultivars Al-624 and CIP-388453-3(B) had the highest tuber zinc content than CIP-388453-3(A) and Al-436. All of the cultivars produced tubers with comparable iron (56 ppm) and manganese (3.8 ppm) contents. Tubers of fruiting plants contained more iron (61 ppm) than tubers of non-flowering and flowering plants (54 ppm) (Table 3). A higher tuber manganese concentration was

Table 3
The effect of cultivar and reproductive growth on tuber microelement nutrition of potato

Main effect	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Cultivar				
CIP-388453-3(A)	20.17 a	54.47 a	3.96 a	13.83 b,c
A-624	21.67 a	59.17 a	4.33 a	20.83 a
Al-436	18.00 b	59.67 a	3.00 a	13.17 c
CIP-388453-3(B)	20.00 a	51.33 a	3.83 a	18.61 a,b
S.E.M.	0.36	3.08	0.42	1.40
Treatment				
Non-flowering	19.25 a	52.75 b	3.75 a,b	14.75 a
Flowering	20.25 a	54.37 b	2.74 b	19.08 a
Fruiting (control)	20.37 a	61.13 a	4.87 a	16.00 a
S.E.M.	0.38	1.38	0.44	1.28

S.E.M.: standard error of the mean. Means within the same column sharing the same letters are not significantly different ($P < 0.05$).

Table 4
The concentrations of macro- and micronutrients in the berries of four potato cultivars

Cultivar	N (%)	P (%)	K (%)	Ca (%)	S (%)	Mg (%)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
CIP-388453-3(A)	2.10	0.40	3.81	0.20	0.40	0.24	23.7	93.7	7.01	23.67
A-624	2.23	0.47	3.93	0.19	0.42	0.29	25.0	96.3	7.33	33.33
Al-436	2.18	0.41	3.73	0.18	0.44	0.26	24.0	94.2	6.33	27.33
CIP-388453-3(B)	2.23	0.40	3.45	0.20	0.67	0.28	23.3	92.7	6.67	32.00
Mean	2.18	0.42	3.73	0.19	0.48	0.27	24.0	94.2	6.8	29.08

observed in fruiting plants (4.9 ppm), followed by non-flowering (3.7 ppm) and flowering plants (2.7 ppm). Reproductive growth did not affect tuber copper (20 ppm) and zinc (16.6 ppm) concentrations.

The macro- and microelements composition of potato berries is presented in Table 4. Mean berry nitrogen content is 2.2%, phosphorus 0.4%, potassium 3.7%, calcium 0.2%, sulphur 0.5%, magnesium 0.3%, copper 24 ppm, iron 94.2 ppm, manganese 6.8 ppm, and zinc 29.1 ppm. The berries contained higher concentrations of macro- and micronutrients than the tubers.

4. Discussion

Potato plant during generative growth phase, depending on the strength of the sinks allocates assimilates to the developing fruit, tubers and other vegetative structures. Under conditions where there is assimilate limitation a competition for a limiting factor among sink organs is imperative. It is speculated that treatments that increase the assimilation of dry matter to the tubers or/and reduces utilization by other organs likely favour tuber growth and increase yield.

Debudded and flowering plants had higher leaf area indices that is attributed to the development of more lateral branches along with expanded leaves in response to apical bud and flower removal. Chatfield et al. (2000) reported that shoot apical meristem maintains its role as the primary site of growth by inhibiting the growth of axillary meristems through the phenomenon called apical dominance and the process is mediated by auxin levels. A progressive decease in LAI was observed in banana after bunch development (Eckstein et al., 1995).

Fruiting plants exhibited higher crop rates compared to the flowering and non-flowering plants. The higher crop growth rates may be attributed to the increased photosynthetic efficiency and enhanced net assimilation rates. In a tomato, Starck et al. (1979) observed increased net photosynthesis and net assimilation rates in fruiting plants compared to deflorated treatment.

Fruit development reduced partitioning of assimilates to the tubers and thereby suppressed tuber growth. This may probably be attributed to the strong assimilate attraction power of developing fruit over tubers. There is evidence that the developing seed and fruit are strong sinks which have priority over vegetative organs in the partitioning of

assimilates (Ho, 1988; Ho et al., 1989). This dominance is believed to be mediated by phytohormones because developing seeds and fruit are rich sources of several plant hormones, including cytokinins, IAA, ABA and GA_3 (Hedden and Hoad, 1985; Brenner, 1987). The efficiency of dry matter accumulation by the tubers was assessed by the partitioning coefficient. Berry development reduced the partitioning coefficient by about 24% as compared to debudded and flowering plants. The partitioning coefficients increased progressively over time indicating that an increasing fraction of available assimilates were allocated to the tuber growth as the crop matures.

In the fruiting plants, the proportion of dry matter partitioned to the fruit varied from 5% to about 9% of the total carbon fixed. The maximum fruit growth rate was observed 4–6 weeks after flower bud initiation. A few days after pollination, potato berries start active growth and attain full development after 6 weeks according to Sadik (1983).

The cultivars exhibited differences with respect to tuber yielding potential. This could be attributed to variation in days to tuber initiation, rate of photosynthesis, efficiency of assimilate partitioning to the tubers (bulking rate) and maturity period. The strong positive correlation of tuber yield with leaf net photosynthesis ($r = 0.97^{**}$), and days to maturity ($r = 0.84$) supports the speculation. Hammes and De Jager (1990) and Gawronska et al. (1990) reported the existence of varietial differences with respect to the rate of net photosynthesis and dry matter production. Biomass production depends upon leaf canopy size and the duration over the growing season to intercepts radiant energy (Van der Zaag, 1984).

Berry development reduced tuber growth rate and ultimately total tuber yield. This indicates that reproductive development had a depressing effect on tuber growth, which may partly be due to competition for assimilates. The strong negative correlation observed between total tuber yield and berry yield ($r = -95^{*}$) and total tuber yield and berry number ($r = -0.99^{**}$) signified that assimilate allocation to the tubers was to a large extent determined by the number and size of the berries. Fruit number and size determined biomass allocation in pepper (Nielsen and Veierskov, 1988) and kiwifruit (Richardson and MacAneny, 1990). Tsegaw and Zelleke (2002) conducted an experiment with the same cultivars and at the same location and found that berry development reduced total tuber yield by about 17% compared to the non-flowering plants. ProundFoot (1965) and Jansky and Thompson (1990) also reported that berry development reduces tuber yield. However, Haile-Micheal (1973) reported no consistent relationship between reproductive growth and tuber yield in potato. The results of the studies on other crops have also indicated that flower and fruit production compete for assimilates and thereby depress the development of underground storage organs such as in sugar beet (Wood and Scott, 1975), onion (Khan and Asif, 1981) and Jerusalem artichoke (Rice et al., 1990).

Variation in tuber number among the tested cultivars indicated that there was a considerable variation in the number of tubers initiated in the course of development. Except for cultivar CIP-388453-3(A), the other varieties increased total tuber number in response to debudding indicating the existence of tuber initiation after flower bud initiation. In favour of this Smith (1931) and Warner (1934) both as quoted by Harris (1978) reported that tuber setting occurred over a considerable period of time. In contrast, Thompson and Kelly (1983) reported that all of the tubers are set at about the same time at flowering.

The increase in the proportion of marketable tubers as a consequence of suppressing berry development may be explained on the bases of absence of competition for limiting factor (assimilate) between developing fruit and tubers. It is speculated that in the absence of reproductive parts, presumably since developing tubers are the predominant sinks, large amount of dry matter is diverted to the tubers which would otherwise be utilized for reproductive growth. As a result, most of the initiated tubers increased in size and attained marketable size. The increase in dry matter content of tubers also substantially contributed for tuber yield improvement as indicated on a strong association between them ($r = 0.73$).

The variation in specific gravity and dry matter content among cultivars can be attributed to the variation in efficiency of diverting of more dry matter to the tubers. Dean (1994) indicated that although tuber dry matter content is influenced by tuber size, environmental conditions and cultural practices, tuber dry matter content appear to be genetically controlled. Lana et al. (1970) and Kushman and Haynes (1971) reported that variation in tuber specific gravity could be due to variation in tissue specific gravity and amount of intercellular space in the tubers. The variation in specific gravity could be due to differences in starch grain size, according to Sharma and Thompson (1956). The highest specific gravity value corresponds with the higher percent dry matter content of the cultivars. Moreover, highly significant positive correlation ($r = 0.99^{**}$) was observed between specific gravity and percent dry matter, thus indicating that specific gravity is a true indicator of the amount of tuber dry matter. In agreement with the present study, Porter et al. (1964) and Fitzpatrick et al. (1964) reported a positive correlation between specific gravity and percent dry matter. On the contrary, however, Wilson and Mlindsay (1969) reported a hyperbolic relationship between them.

Fruit development decreased tuber specific gravity and dry matter content may be explained on the basis of competition for assimilate between developing berries and tubers. It is speculated that in the absence of reproductive parts, presumably since developing tubers are the predominant sinks, large amount of dry matter is diverted and accumulated in the tubers. The strong negative relations observed between fruit yield and tuber dry matter content ($r = -0.82$) and fruit yield and specific gravity ($r = -0.83$) support the speculation. Reproductive growth reduced tuber specific gravity and dry matter content, according to Tsegaw and Zelleke (2002).

Potato berries contained higher macro- and micronutrients than the tubers indicating that they are strong sinks for mineral elements. Cultivars differed in tuber macro- and micronutrient concentrations. Cultivar Al-624 produced tubers containing higher concentration of almost the entire major and trace elements than the other cultivars. Fruit development increased the concentration of tuber N (expressed in crude protein), P, K, Mg, Fe, and Mn without affecting Ca, S, and Cu concentration. Cultivar Al-624 was characterized by having higher concentrations of minerals in the tuber and the highest rate of leaf transpiration. Fruiting plants exhibited higher tuber nutrient content and rate of transpiration. This association strengthens the hypothesis that an increased rate of transpiration enhances the rate of mineral uptake. Salisbury and Ross (1992) reported that growing plants in greenhouses where there is reduced transpiration due to high humidity may cause calcium deficiencies in certain tissues and too rapid transpiration can lead to a toxic build up of certain elements. In the current study, it was found that

fruit development reduced tuber yield by reducing both tuber size and number. Hence, the observed lower concentration of macro- and micronutrients in relatively larger tubers of the debudded and flowering plants may partly be a consequence of ''dilution effect''.

5. Conclusion

Results of the current experiment demonstrated that cultivars exhibited differences with respect to tuber fresh mass, tuber number, size distribution, specific gravity, dry matter content, and nutrient composition. Fruit development reduced leaf area index, tuber growth rate and partitioning coefficient while increasing crop growth rates and net assimilation rates. Ultimately decreased tuber yield as well as dry matter content. Prevention of berry set may increase tuber yield and dry matter content. Hence, simple and economical means to control flowering and berry set should be investigated. It is suggested that the effects of flower-controlling agents such as MCPA, ethephon, naphtylacetamide, and 2,4-D-amide must be studied.

Acknowledgements

The study was sponsored by Alemaya University, Ethiopia, through a fund procured from World Bank. The authors are grateful to Feleke, A., Meimuna, I., Almaz, T., and Abeba, H. and others who directly or indirectly involved in the execution of the field and laboratory work.

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