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Assessment of potato plant development from Minitubers

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Abstract. In production of minitubers, manipulation of their weight by modifying production method is common. Under field conditions plant development from minitubers can be affected by their weight, as well as cultivar. This objective of this study was to compare plant development from four minituber weight classes (MtC) (3 to 4.99 g, 5 to 9.99 g, 10 to 19.99 g, and > 20 g) with broken apical dominance of cultivars 'Monta', 'Prelma' and 'Mandaga'. 'Prelma' and 'Mandaga' had a similar development pattern, and minitubers > 20 g required significantly less growing degree days (GDD) to emerge than minitubers from the lightest classes. The heaviest minitubers needed on average 176 GDD for 50% emergence and 207 GDD were needed for the lightest class. The difference in GDD between the marginal MtC was more pronounced in period between 50 and 80% emergence. MtC did not affect the final rate of emergence. Number of above ground stems (1.4–4.0) was significantly affected by MtC. 'Monta' had significantly different development – delayed emergence, lower emergence rate, less above ground stems, faster canopy closure. Our study showed that plant development was significantly affected by MtC and cultivar. Differences between MtC were more pronounced under adverse meteorological conditions.

Key words: Field performance, non-emergence, potato ageing, number of stems, GDD.

INTRODUCTION

Minitubers are small tubers produced from in vitro derived potato plantlets (Struik, 2007) in protected environments at the initial stage of potato (*Solanum tuberosum*) seed production worldwide. The average weight of minitubers is affected by the production technology. Minituber field performance can be significantly affected by their weight (Struik & Lommen, 1999; Barry et al., 2001). Therefore, it is relevant to know the minimal minituber weight appropriate for further field multiplication under particular conditions.

Plant emergence is an important phase of potato development. In regions, where potatoes are planted relatively late and cloudiness is common, plants capture less global radiation than would be desirable (Haverkort & Struik, 2015). The highest level of solar radiation, which is a key factor for photosynthesis, is reached in May and June. Therefore, in Northern Regions, fast emergence of plants and quick canopy closure are crucial for the further growth and yield formation under short growing season conditions.

Time to emergence in days after planting (DAP) can be very variable and tubers of different physiological status may have a different lag period between planting and emergence. Lag period decreases with increasing temperature (Firman et al., 1992). Delayed emergence and slow initial growth is typical for plants developing from minitubers. Thus, Fulladolsa et al. (2017) reported a 14 day delay in comparison to conventional tubers. Moreover, the smaller the minituber is, the longer dormancy it has and it can affect plant emergence (Hagman, 1990; Lommen & Struik, 1994). Hagman (1990) compared minitubers with 10 and 30 mm diameters and observed significantly delayed emergence of the smaller ones.

The main environmental factor driving potato emergence is temperature (Haverkort et al., 2015). The growing degree days (GDD) approach may be an accurate way to discriminate the differences in plant emergence between cultivars and weight classes of minitubers (MtC) over two and more growing seasons. The necessary amount of GDD for emergence of minitubers in the field is not widely studied.

One of the main traits defining the physiological status of the seed tuber and potato plant growth vigour is number of stems per emerged plant. The number of stems is a crucial trait as it influences tuber number both per plant and per unit area. Genotype and seed size are the factors most likely affecting the stem number per plant (Struik et al., 1990). In addition, stem number can be reduced when apical dominance of the sprouts is not broken (Wurr et al., 2001).

Few studies on field performance of minitubers involve the assessment of the number of stems. Additionally it is rarely known if sprout apical dominance has been broken.

Minitubers produce significantly less stems than conventional tubers (Lommen & Struik, 1994; Gopal et al., 2002). In previous studies, one plant from minituber produced 1–2 stems (Lommen & Struik, 1994; Külen et al., 2011), while in other studies 2– stems (Gopal et al., 2002; Ozkaynak & Samanci, 2006) were produced.

The canopy closure (or ground cover) phase characterizes radiation interception, which reaches 100% only when full ground cover is established (MacKerron & Waister, 1985; Haverkort et al., 2015). Advanced canopy closure can give a relative increase in potential yield (MacKerron & Waister, 1985; Haverkort & Struik, 2015). Development of the canopy can be estimated as DAP or days after emergence (DAE). Plant emergence is the most appropriate starting point for assessing further phases of potato development including canopy closure (O'Brien et al., 1998).

Little information exists on the field performance of minitubers in Northern Europe and in Baltic states in particular. Planting of minitubers can be conducted relatively late in this region and growing season is very short. Heavy virus pressure caused by ware potato production traditions in hobby gardens is limiting factor for potato seed production in Baltic states. Less field generations of potato seed can help solving this obstacle The production of large quanities of minitubers with good field performance can reduce number of field multiplication generations and increase availabilty of high quality potato seed of locally breed cultivars.. The objective of this study was aimed to compare plant development of minitubers from three cultivars and four weight classes with broken apical dominance.

MATERIALS AND METHODS

A three year (2014–2016) study was carried out at Priekuli Research Centre (PRC) of Institute of Agricultural Resources and Economics, Latvia (57°18′ N, 25°20′ E). Three cultivars of different maturity bred in PRC were used for the study ('Monta' – early, 'Prelma' – medium early and 'Mandaga' – medium late).

Minitubers were obtained from *in vitro* plantlets grown in fertilized peat in greenhouses of PRC. Minitubers were stored nine months including seven months cold storage (3 °C). Two weeks before planting, minitubers were de-sprouted and then pre-sprouted under diffused natural light.

Each year, minitubers of weight classes 3 to 4.99 g, 5 to 9.99 g, 10 to 19.99 g, and > 20 g were planted by hand in a sandy loam soil in the second part of May. Winter cereals were used as the previous crop in all three years.

A randomized split-plot design was used with the cultivar as the main plot and MtC as the subplot. The trial was replicated three times in 2014 and four times in 2015 and 2016. Minitubers were planted at 0.7 m between rows using 0.2 m in-row spacing. Each sub-plot consisted of 48 minitubers (12 tubers × 4 rows). Plant development was evaluated only in two inner rows in order to avoid possible effect of the competition between plots.

Fertilizers were broadcasted on the surface of the field one week before planting at the rate of 60 kg N ha^{-1}, 55 kg P_2O_5 ha^{-1} and 90 kg K_2O ha^{-1}. Broadcasting of the fertilizers was followed by the deep tillage. Plant protection measures were performed as needed and were aligned with the integrated pest management practice.

Plant emergence was assessed two to three times a week and the date of the emergence was considered when 50% of plants in the plot were visible above the soil surface (MacKerron & Waister, 1985). Observations of emergence were continued at previously mentioned intervals up to 50 days after planting (DAP) to determine the final number of emerged plants. Simultaneously, the number of days to 80% emergence (E80%) was assessed to evaluate further plant development. Plant emergence rate was recalculated to GDD starting from the 2nd day after planting. As plant emergence was assessed in early mornings, the recorded date of emegence was excluded from the calculation of GDD.

Canopy closure was estimated when at least 90% of plants met within rows and data were recorded as days after 50% emergence (DAE50%). Data on GDD was added to analysis only for the reference, as the GDD approach for prediction of canopy development fits better under conditions not subjected to environmental stresses (Haverkort et al., 2015).

The canonical formula for GDD calculation was applied according to McMaster & Wilhelm (1997), and 2 °C was used as a base temperature (Tbase) for pre-sprouted tubers (MacKerron & Waister, 1985).

The number of above ground stems was determined for each sub-plot two weeks before harvesting.

Effects of the two main factors – cultivar and MtC were determined by analysis of variance (ANOVA) using SPSS version 18.0. The LSD test at $\alpha = 0.05$ probability level was used to compare group differences. The effect of growing year was treated as a random factor. When the appropriateness of GDD approach was examined, one way ANOVA on year effects was performed.

RESULTS AND DISCUSSION

Plant emergence

Time to E50% and E80% expressed both in DAP and GDD was significantly affected by cultivar ($P < 0.001$) and MtC ($P < 0.05$). The largest proportion of variation was attributed to the effect of cultivar (36–61%), while MtC explained only 5–9% of variation.

P-values presented in Table 1 confirm the significant effect of growing year on time to plant emergence for all studied cultivars when expressed in DAP. This confirms the statement that time to emergence can be very variable between years (Firman et al., 1992) and temperature is the main factor driving plant emergence (Haverkort et al., 2015). Table 1 shows that GDD approach can be more conservative to describe the time required for potato emergence, as the effect of the growing year was not significant for two cultivars

Table 1. *P*-values for the effect of growing year on plant emergence to 50%, to 80% and within rows canopy closure expressed in DAP and GDD for three cultivars

Cultivar	E50%		E80%		Canopy closure within rows	
	DAP	GDD	DAP	GDD	DAE50%	GDDAE50%
Monta	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Prelma	< 0.001	**0.618**	< 0.001	**0.285**	< 0.001	< 0.001
Mandaga	< 0.001	**0.389**	< 0.001	**0.425**	< 0.001	< 0.001

For all cultivars, it took more days to emerge in 2015 (Fig. 1), when mean air temperature in the end of May and in the beginning of June was lower when compared with that in other years and the long term average data. Minitubers of all weight classes below 20 g of ‘Prelma’ and ‘Mandaga’ had significantly ($P < 0.05$) lower emergence rate 20 DAP than MtC > 20 g. MtC did not affect emergence rate of ‘Monta’ significantly up to 30 DAP in 2015. All MtC of ’Monta’ continued to emerge after 30 DAP and minitubers from two largest weight clases had significantly higher emergence rate at 41 DAP. In 2014, due to higher than average air temperature, plants emerged very rapidly and no effect of MtC of ’Prelma’ and ’Mandaga’ was observed on emergence rate in any of the evaluated periods (Fig. 1). In 2016, emergence was also fast, however, a significant effect of MtC was observed 20 DAP for ’Monta’ and ’Prelma’. However, this effect was not as pronounced as in 2015. In general, MtC had a more clear effect on differences of plant emergence pattern when weather was cold. Differences between MtC were observed until 20 DAP, but shortly before 30 DAP only insignificant differences remained in 2015 and 2016. Only for ‘Prelma’ in 2015 and for ‘Monta’ in 2016 was the effect of MtC on plant emergence rate 30 DAP still significant ($P < 0.05$).

No significant differences in emergence to 50% and to 80% expressed in GDD were observed for ‘Prelma’ and ‘Mandaga’ between the years (Table 1). These results agree with a statement by Haverkort (2007) that some developmental processes including sprout growth have constant rates to reach a certain phase. However, due to unexplained factors ‘Monta’ showed an atypical growth response as significantly more ($P < 0.001$) GDD were required by Monta on 2015 than on other years of the study to emerge both to E50% and E80%.

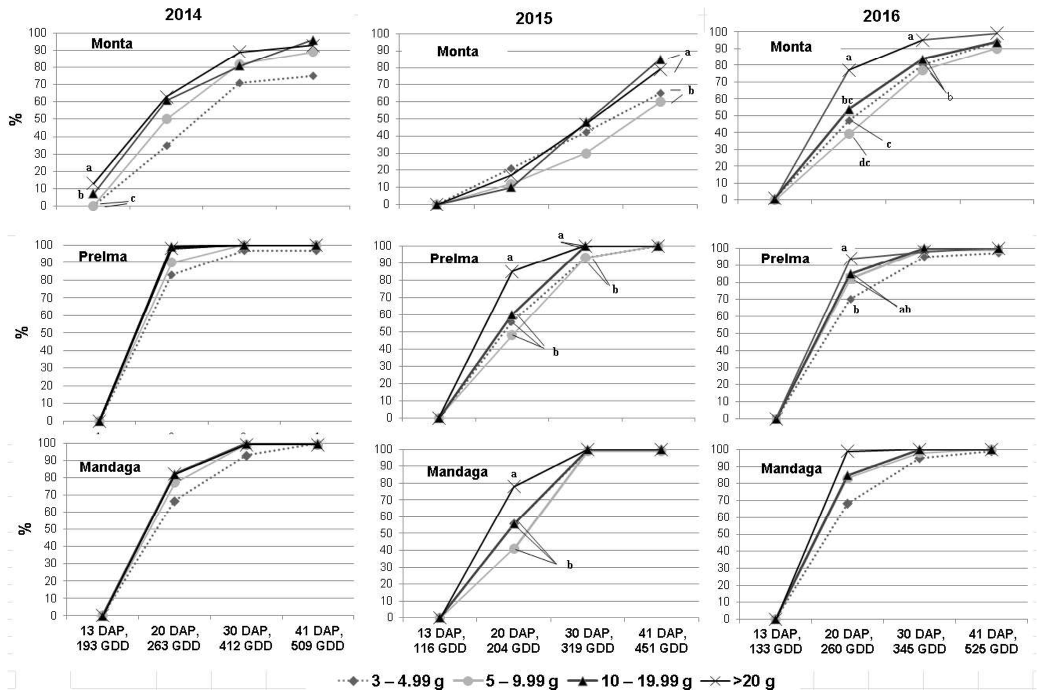

Figure 1. Emergence (%) pattern of plants from minitubers depending on cultivar and weight class of minitubers. *Different letters indicate significant differences (P < 0.05) between weight classes of minitubers within cultivar and within year. Samplings not marked with letters are not significantly different.*

GDD accumulated by plants to reach E50% and E80% was significantly ($P < 0.001$) affected by cultivar and MtC. 'Monta' differed significantly from 'Prelma' and 'Mandaga'. The two latter cultivars accumulated similar amount of GDD to E50% and to E80% (Fig. 2). The interaction between the main factors was not significant ($P = 0.992$ and $P = 0.993$ respectively).

Plants from each MtC of 'Monta' accumulated significantly more GDD (on average 83 GDD more) to reach E50% than plants of 'Prelma' and 'Mandaga'. The difference in GDD became even more pronounced for E80% (on average 136 GDD more needed for 'Monta'). The effect of cultivar corresponds to previous findings showing a genotype effect on accumulated GDD needed to reach certain development phases (Streck et al., 2007). In a study with conventional tubers Jefferies & MacKerron (1987) found on average 378 GDD required for 'Maris Piper' to reach E50% with Tbase 0 °C in formula. Similar results have been published by O'Brien et al. (1998). Even when their data is recalculated to Tbase 2 °C, the value (~ 271–298) is still higher than average number of GDD in our study. Only GDD to E50% for three lightest MtC of 'Monta' can be compared to those obtained by Jefferies & MacKerron (1987) and O'Brien et al. (1998). These remarkable differences could be affected by cultivar. In addition, the storage temperature did not exceed 4 °C in both examples and no information on sprout development is provided. Firman et al. (1992) reported that well sprouted cold tubers can reduce thermal time by 60 GDD (Tbase 1 °C), but pre-warmed tubers (no data on sprouting specified) can reduce thermal time by 15 GDD (Tbase 1 °C). Consequently, we can assume that planting of well sprouted and warm tubers can reduce GDD requirement even more. This explains relatively small requirement of GDD even for smaller minitubers to emerge in our experiment.

We found that significantly more GDD for emergence of 'Monta' in comparison with other cultivars were required only by minitubers. In experiments where conventional tubers are used, 'Monta' does not have delayed emergence in comparison with 'Prelma' and medium late cultivars (Dr. I. Skrabule, PRC, personal communication). The actual storage conditions, storage time and relatively big size of minitubers often causes early sprouting. As only minitubers without sprouts can be certified, then common practice under described conditions is removing (de-sprouting) of the etiolated sprouts. During the de-sprouting the apical dominance is broken and this help increase the number of stems under the field conditions. However, the effect of early sprouting on field performance of some cultivars can be negative (Struik et al., 2006). Before de-sprouting, shrinkage of minitubers of 'Monta' was quite pronounced. Besides, minitubers had quite strongly established etiolated sprouts. These may be signs of advanced ageing and early cultivars are prone to very high rate of ageing (Struik et al., 2006). Possibly minitubers of 'Monta' are more sensitive to storage conditions than conventional tubers.

Emergence of lighter minitubers to E50% was delayed in comparison to heavier minitubers (Fig. 2). Lighter tubers have longer dormancy (Van Ittersum, 1992), therefore, they are physiologically younger and emerge later than heavier ones as reported by Knowles & Knowles (2006), Oliveira et al. (2014) and other researchers. Our study confirms previously described associations on minitubers as well.

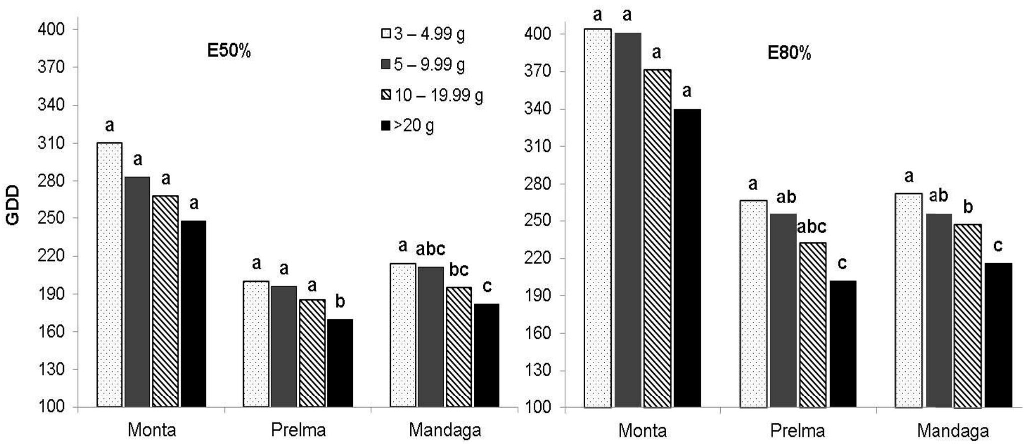

Figure 2. Accumulated GDD to 50% emergence (E50%) and 80% emergence (E80%) (*Different letters indicate significant differences (P < 0.05) between weight classes of minitubers within cultivar. Analysis was done separately for E50% and E80%*).

For 'Prelma' and 'Mandaga' the emergence gap to E80% between the lightest and heaviest minitubers was more pronounced than from planting to E50% (Fig. 3). It took longer for the remaining smaller minitubers to emerge from E50% to E80%. Thus, the difference between marginal MtC of 'Prelma' in GDD value to E80% increased two times when compared to difference in GDD value to E50%. Performance on 'Mandaga' was similar to that of ‘Prelma’. Our results agree with Lommen & Struik (1994) who found that more time is needed for lightest minitubers to emerge after E50%. A similar difference pattern in emergence to E50% and E80% was observed for ‘Monta’.

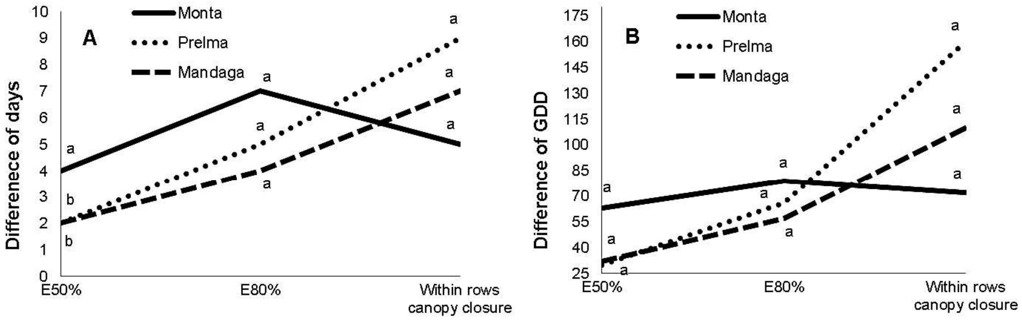

Figure 3. Difference in days (A) and GDD (B) between the smallest (3–4.99 g) and the largest (> 20 g) weight class of minitubers required to reach E50%, E80% after planting (emergence gap) and to reach within rows canopy closure after emergence (canopy closure gap). *Different letters indicate significant differences (P < 0.05) between cultivars within the observation.*

In research by Allen et al. (1992), time to E50% of smaller conventional tubers increased with planting depth. Fulladolsa et al. (2017) agrees, as in their study, rows were hilled after the time when most of the conventional tubers had emerged. Authors assume that hilling may delay emergence of minitubers despite of shallower planting. Our study is partly in line with this statement. In the case of ‘Prelma’ and ‘Mandaga’, minitubers from smaller MtC usually emerged to E80% only after the hilling, while during all study years for ‘Prelma’ and two years for ‘Mandaga’ minitubers from the MtC > 20 g emerged before hilling. All MtC of ‘Monta’ emerged to E50% mostly after hilling, therefore hilling does not explain differences in emergence gap between the smallest and largest MtC.

Percentage of emerged plants of ‘Prelma’ and ‘Mandaga’ was not significantly affected by growing year, and MtC (Table 2). In contrast, significantly less plants of cultivar ‘Monta’ emerged in 2015 when compared with other years, and the significant effect of MtC on plant emergence rate was observed in 2015 (Table 2).

Table 2. Percentage of emerged plants produced by minitubers of five weight classes, 2014–2016

Weight class of minitubers, g	**Emerged plants 50 DAP, %**				Means within weight class of minitubers
	Monta 2015	2014–2016	Prelma 2014–2016	Mandaga 2014–2016	
3–4.99	68^{b}	$\mathbf{82}^{a}$	$\mathbf{99}^{a}$	$\mathbf{99}^{a}$	93^{a}
5–9.99	66^{b}	$\mathbf{82}^{a}$	$\mathbf{100}^{a}$	$\mathbf{99}^{a}$	94^{a}
10–19.99	86^{a}	$\mathbf{92}^{a}$	$\mathbf{100}^{a}$	$\mathbf{100}^{a}$	97^{a}
➢ 20	84^{a}	$\mathbf{92}^{a}$	$\mathbf{100}^{a}$	$\mathbf{100}^{a}$	97^{a}
Means within cultivar	$\mathbf{87.0}^{A}$		$\mathbf{99.8}^{B}$	$\mathbf{99.5}^{B}$	×

Different letters indicate significant differences (P < 0.05) between data within column. Different capital letters indicate significant differences (P < 0.05) between means within cultivar.

Results on percentage of emerged plants partly agree with those of Lommen & Struik (1994) and Barry et al. (2001) who did not find a significant effect of weight of planted minitubers on percentage of plants emergence and reported 82–100% emergence depending on growing season.

The low emergence rate of cultivar 'Monta', especially in 2015 (Table 2), when only 66–86% of plants emerged, may be explained by the physiological status of planted minitubers. A phenomenon, the so called "non-emergence" of too old tubers, has been previously demonstrated (Bodlaender & Marinus, 1987; Oliveira et al., 2014). Hagman (1990), as well, found this phenomenon investigating minitubers. Bodlaender & Marinus (1987) and Hagman (1990) found that non-emergence was significantly affected by cultivar. Nutrition reserves of minitubers can be lost during sprout formation (Lommen & Struik, 1993) and probably due to early sprouting and subsequent de-sprouting, 'Monta' had a lower emergence rate than other cultivars. A significantly lower percentage of emerged plants from two lighter MtC in comparison to two heavier MtC confirmed this assumption. However, minitubers of 'Monta' had slower emergence as well and this is in contrast to findings reporting earlier emergence of older tubers (Knowles & Knowles, 2006; Oliveira et al., 2014). These contradictions do not allow us to claim that minitubers of 'Monta' were too old to have good emergence rate. More research on this cultivar is necessary.

Number of above ground stems

The main factors (cultivar and MtC) explained more than 77% of the variance in number of above ground stems, MtC being a dominant factor determining 59% of variance. Significant interaction between the main factors was found ($P < 0.001$).

Mean values within MtC over cultivars (Table 3) were similar to those obtained by Gopal et al. (2002), Ozkaynak & Samanci (2006), and Wrobel (2015). Relatively large minitubers were used in the mentioned studies (20–30 g, up to 18 g and 15–30 mm respectively), which resulted in 1.3–5.0 stems per plant depending on cultivar. Heavier minitubers produced significantly more main stems (Ozkaynak & Samanci, 2006). In contrast, only 1–2 stems per plant and no significant differences between different MtC were reported in the study of Lommen & Struik (1994), when very small minitubers were used (0.13–3.99 g).

Table 3. Above ground stems per emerged plant depending on MtC and cultivar, 2014–2016

Weight class of minitubers, g	Number of above ground stems per emerged plant			Means within weight class of minitubers
	Monta	Prelma	Mandaga	
3–4.99	1.4^{c}	1.6^{d}	1.7^{d}	**1.6^{d}**
5–9.99	1.5^{c}	2.0^{c}	2.2^{c}	**1.9^{c}**
10–19.99	1.8^{b}	2.7^{b}	2.9^{b}	**2.4^{b}**
> 20	2.4^{a}	4.0^{a}	3.9^{a}	**3.4^{a}**
Means within cultivar	1.8^{A}	2.6^{B}	2.7^{B}	×

Different letters indicate significant differences (P < 0.05) between data within columns. Different capital letters indicate significant differences (P < 0.05) between means within cultivar.

In our study, the number of above ground stems increased significantly with the increase of MtC both over cultivars and within each cultivar. Heavier tubers are physiologically older, therefore, usually have more stems (Knowles & Knowles, 2006; Oliveira et al., 2014).

Canopy closure

Full ground cover was observed only in few plots over the three study years, therefore, canopy closure within rows were assessed to compare plant development after emergence.

Time to within rows canopy closure expressed in DAE50% was significantly determined by cultivar and MtC ($P < 0.001$). No significant interaction between main factors was detected ($P = 0.652$). Across cultivars and MtC means less time for within rows canopy closure was required in 2015, when plants had significantly delayed E50% expressed in DAP. In 2014 and 2016, on average 39 DAE50% were required to reach within rows canopy closure, while significantly more GDD were accumulated in 2016 when compared to 2014 (556 and 445 GDD respectively). This tendency was similar for all cultivars and all MtC separately, except MtC > 20 g of 'Prelma'. These results confirm the statement that thermal time approach to estimate canopy closure is not consistent (Streck et al., 2007). In the last 10 days of June 2016, 85.6 mm of rain (309% of long term average precipitation) was recorded and 58 mm fell during 24 hours. Heavy rainfall caused water logging in field and plant development slowed down, despite optimal temperature.

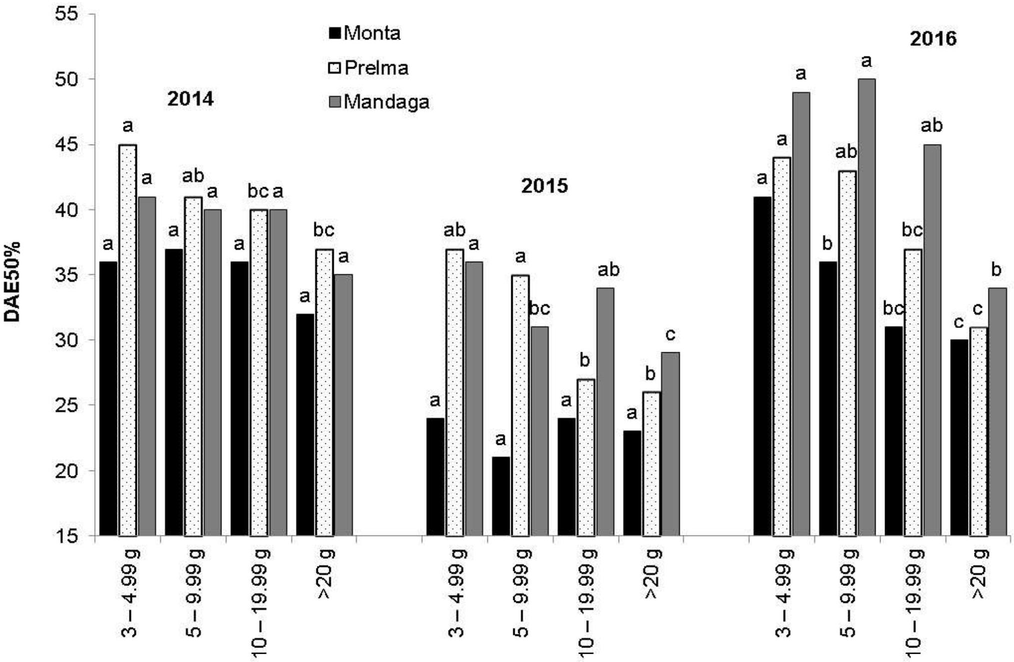

Figure 4. Time to within rows canopy closure expressed in DAE50%. *Different letters indicate significant differences (P < 0.05) between MtC within cultivar and within year*.

Data in Fig. 4 shows faster within rows canopy closure of plants grown from heavier minitubers, however, these differences in all years of the study were significant only for 'Prelma' ($P < 0.05$), while for ' Monta' significant effect of MtC on canopy closure was observed only in 2016, but for 'Mandaga' in 2015 and 2016. Barry et al. (2001) reported that plants from smaller minitubers may have a 14 day delay in ground cover when expressed in DAP, or they even do not reach full ground cover. Similarly our results showed DAE delay for the MtC 3–4.99 g (10, 8, 5 days for 'Prelma', 'Mandaga', 'Monta', respectively). Radouani & Lauer (2015) did not find significant differences in ground cover 30 DAP depending on minitubers size. They used 15–20 g and heavier minitubers. Our results agree with theirs, because even for 'Prelma' significant differences between two heavier MtC were not found.

Despite the significant delay of plant emergence of 'Monta', the earliness of this cultivar became apparent when plants reached 90% within row canopy closure in fewer days after E50% than plants of 'Prelma' and 'Mandaga'.

The difference between the marginal MtC of 'Prelma' and 'Mandaga' in DAE50% to within row canopy closure was more pronounced than it was to emergence (Fig. 3) Stem development of lighter minitubers became slower mostly because the tuber nutrition reserves were spent during the emergence (Lommen & Struik, 1994) and the mother tuber role was lost earlier. Results for 'Monta' were not consistent with other cultivars tested.

CONCLUSIONS

This study showed that the effect of weight class of minitubers on plant development was more pronounced under adverse meteorological conditions when minitubers from the lightest classes had much slower initial growth. Overall this study showed that plants from lighter minitubers had slower emergence and canopy closure (even if not significant), and less above ground stems. Nevertheless, the final emergence rate was not significantly affected by the weight class of minitubers.

The significantly different response of 'Monta' relative to the other cultivars tested revealed the necessity for studying each cultivar for minitubers field performance in detail. Moreover, this early cultivar showed an unforeseen response such as more days after planting and more GDD required to emerge, when compared to medium early 'Prelma' and medium late cultivar 'Mandaga'. Moreover, 'Monta' had significantly lower emergance rate and non- emergence phenomenon was observed especially in 2015. More attention should be given to the storage of 'Monta' minitubers to slow the ageing.

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