Original Research Article

EFFECT OF TEMPERATURE REGIMES ON MORPHOLOGICAL DEVELOPMENT OF SELECTED CANOLA (*Brassica napus*) GENOTYPES

ABSTRACT

Seven canola genotypes selected from early and mid-maturing groups of canola genotypes presently planted in the Western Cape canola production area were grown in 3 litre plastic bags filled with a mixture of sand and compost at ratio of 1:1 and irrigated with fully balanced nutrient solution at EC=2.0 in two glasshouses at night/day temperature regimes of 10/15^{o}C and 15/20^{o}C. Plant heights were measured at 14 days interval from 28 to 84 days after planting (DAP). Plants were sampled for leaf area (LA) and above ground dry mass (DM) at budding, flowering and seed physiological maturity stages. Plant growth rates (PGR) from planting to budding, from budding to flowering and from flowering to physiological maturity growth stages were calculated. Relative growth rates (RGR) and net assimilation rates (NAR) from budding to flowering and from flowering to physiological maturity stages were also calculated. Days after planting, GDD and PTU at budding, flowering and physiological maturity were correlated with leaf area, dry mass, number of pods plant-1 and pod dry mass plant-1 at budding, flowering and physiological maturity stages to determine whether there were relationships between the variables. The study showed that by increasing night/day temperature from 10/15^{o}C to 15/20^{o}C plant height, number of leaves plant-1 at budding stage, leaf area at budding , plant growth rate (PGR) from planting to budding stage and relative growth rate (RGR) from budding to flowering stage were increased. However, PGR from budding to physiological maturity, RGR from flowering to physiological maturity, net assimilation rate (NAR) from budding to flowering stage, leaf area at flowering and physiological maturity stages , as well as number of flower stems, number of pods plant-1, above ground total dry mass at flowering and physiological maturity stages were decreased. Pod dry mass at physiological maturity decreased by 22.24% to 40.35% for different genotypes which clearly demonstrated the variations in sensitivity of canola genotypes to increasing night/day temperatures and also indicates that canola crop can be genetically improved for heat tolerance.

KEYWORDS: Temperature, Canola, Morphology, Genotypes.

INTRODUCTION

Canola (*brassica napus*) is increasingly becoming an important field crop in South Africa. It can be used to produce high quality cooking oil and margarine, animal feed, biofuel (Anonymous 2006) and in crop rotation systems to break the disease chain and improve weed management (Burton *et al*. 2008). It is a native of Canada and is characterized by seeds which contain oil that has a low erucic acid content. Such oils contain less than 2% erucic acid, the solid component of the seed must contain less than 30 micromoles of any one or any mixture of 3-butenyl glucosinolate, 4-pentyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate and 2-hydroxy-4-pentyl glucosinate per gram of air-dry oil free solid (Anonymous 2006).

In Canada canola is planted in late April or early May, where-after it grows rapidly during the short summer season that *et al* has long warm days and is harvested in end September or early October. Although canola will flower much sooner at daylight lengths of 16 to 18 hours, it will eventually also flower at much shorter daylight lengths but after a longer period, (Kirkegaard *et al*. 2012). In South Africa and Australia canola is also planted in April or May but the growth take place during winter period with daylight lengths of 9.5 hrs in May to 12 hrs in September and is harvested during October. The phenological development affects the success of canola production and is largely controlled by temperature (Morrison *et al*. 1992). Accurate timing of these phenological events is generally considered the most important factor determining crop adaptation and maximum yield in a particular environment (Fischer 1979, Richard 1991).

In general development of an annual crop from emergence to maturity can be divided into three major phenological developmental phases: from emergence to flower buds initiation-vegetative development, from floral buds initiation to anthesis-reproductive development and from anthesis to physiological maturity -seed filling (Craufurd and Qi, 2001, Ritchie, 1991, Siebert and Ewert 2012). However, canola developmental stages can be divided into six phases according to Harper and Berkenkamp (1975): Phase 0-Pre-emergence, Phase 1-Seedling, Phase 2-Rosette, Phase 3-stem elongation, Phase 4-flowering, Phase 5-Seed maturation. Under climate change scenario, increase in both the mean and extremes of temperature are expected for many parts of the world (IPCC 2001). These changes can impact largely on the growth and phenological development of crops. Temperature and to less extent photoperiod have been reported to be major environmental factors that determine the timing and duration of each of the phenological phases in the physiological development of crops (Roberts *et al*. 1993). Many models have been developed to explain the phenological phases that take place during growth and development of crops (Alocija and Ritchie 1991, Matthews and Hunts 1994), while the physiological mechanisms that govern the transition from one phenophase to another are strongly influenced by environmental factors and have been described using photothermal models (Summerfield *et al*. 1991).

Photoperiod has been reported to be principally factor that determines the time of floral initiation and hence onset of anthesis in many crop species (Burtero *et al*. 1999). Photoperiod, for example affects floral development of rice (*Oryza sativa* L.) (Coolhaas and Wormer 1953), caryopteris (Piringer *et al*. 1963), wheat(*Triticum aestivum* L.) (Slafer and Rawson 1994), barley *(Hordeum vulgare* L.) (Kernich *et al*. 1996) and quinoa (*Chenopodium quinoa willd*) (Burtero *et al*. 1999). However, it is not clear whether

the duration of the reproductive phase is affected directly (immediate response) by the photoperiod experienced during this phase or indirectly (delayed response) by photoperiod experienced in earlier developmental phases. The delayed effects on reproductive development could be because of the fact that more leaf primordial are formed under an extended duration of the vegetative period and this means that anthesis has to wait longer because more leaves have to appear and all the leaves must appear before anthesis will occur (Kiniry *et al*. 1992). The underlying assumption here is that the total leaf number cannot be altered after the end of vegetative growth phase during anthesis and seed filling. However, Slafer and Rawson (1995) and Kernich *et al*.(1996) have shown that time from the end of leaf appearance to anthesis is affected by the photoperiod after floral initiation, but not leaf number in wheat and barley respectively.

Ritchie and Smith (1991) reported that temperature regime is a major factor controlling the rate of leaf appearance. Hence "phyllochron" is defined as a constant interval of thermal time between successive leaves appearance. However the effect of temperature on the time interval between successive leaves' appearance (phyllochron) is crop specific for the different field conditions (Cao and Moss, 1989). For Chenopodium photoperiod was reported to decrease the ''plastochron" (the time between initiation of two successive primordia) with transfers from inductive to marginally or vice versa (Thomas, 1961). A photothermal duration effect on seed maturation processes has been demonstrated for soybean (*Glycine max* (L) *merril*), peanut (*Arachis hypogeal L*), bambaranut (*Vigna subterrenea* (L) *verdc*), rice (*Oryza sativa*), muccuna spp, maize (Z*ea mays L*), sorghum (*Sorghum bicolor*) and field pea (P*isum sativum*) (Bagnall and King, 1991, Birch et al 1997, Craufurd and Qi 2001, Craufurd et al. 2003, Linnemam 1993, Morandi et al. 1998, Poggio *et al*. 2005 and Qi *et al*. 1998,). It has also been reported that photothermal regime influence vernalisation sensitivity of crops. Plants vernalised for 50 days showed greater response to photoperiod than those vernalised for 15 days. As the duration of stem enlongation lengthened in photoperiod-sensitive genotypes by exposure to less inductive photoperiods, a higher number of fertile florets at anthesis are produced, leading to an increased grain number and thereby to higher yield (Gonzalez *et al*. 2003). The timing of leaf emergence, flowering and seed filling as influenced by photothermal exposure and duration are critical factors in crop production, especially in the Mediterranean environment with its characteristic period of increasing temperatures and water stress that occur towards the end of the growing season. This has been extensively studied in other cereal crops as highlighted earlier in this introduction, but such study has not been carried out in canola being that it is relatively a new crop in South Africa. Therefore this study was conducted to determine

the effect of temperature regimes on the morphological development of canola in order to maximally exploit its productive potentials, and enhance its agronomic management. In addition, results obtained from this study will serve as a tool for canola breeding for the South African climatic conditions and also provide information with regard to its production potential in new production areas.

1. MATERIALS AND METHODS

The study was conducted in glasshouse controlled environment at department of Agronomy, University of Stellenbosch, South Africa. Experiment was laid out as a completely Randomized design (CRD) with two temperature regimes and seven genotypes of canola as treatments. Four replications were used and single plant represents an experimental unit. Provision was made for three sampling times.

Seven genotypes of canola evaluated were Hyola 571 CL, AGAMAX, 45Y86, 44Y84, Hyola 50, 43Y85, and Hyola 575 CL. These were planted (four seeds per 3 litre plastic bags filled with the mixture of sand and compost at ratio of 1:1 and irrigated with fully balance nutrient solution at 2.0 EC) in two glasshouses. The genotypes were selected based on the duration of their maturity. 45Y86 and Hyola 50 were mid-maturing genotypes; 44Y84 was mid-early; while, 43Y85, AGAMAX, Hyola 571 CL and Hyola 575 CL were early maturing genotypes. During the seedling stage, plants were thinned to one per bag. The two temperature regimes were set at 15/20^{o}C and 10/15^{o}C night/day temperatures respectively. The plants were irrigated twice a day to re-fill the bags to field water capacity.

Daylight length (number of hours of sunshine) was obtained from the South African weather service (http//www.Weathera.com). Crops were planted on 11 February 2014 and the final harvest was done on 14 July 2014 with the result that the day length varied between 13:20 hours at planting and 10:48 hours during the final harvest. The light intensity in the glasshouses and outside exposed environment were measured weekly at 12h00n from the seedling stage of the plants and averages of 211.6 µmolm-^{2}s-^{1} for 15/20^{o}C glasshouse, 249.1 µmolm-^{2}s^{-1} for 10/15^{o}C glasshouse and 481.5 µmolm-^{2}s^{-1} for outside environment were obtained. Temperature loggers were put in each glass house to record the actual temperature of the glass houses to make sure that the set temperatures were achieved.

The number of days required to reach the following growth stages (GS) according to Harper and Berkenkamp (1975) were recorded: Seedling stage (GS 1.0); first true leave (GS 2.1); visible inflorescence at center of rosette or budding (GS 3.1); first flower open (GS 4.1); beginning of seed filling) (GS 4.4); lower pods filled to full size and become translucent (GS 5.1); and seeds in lower pods turn brown which

is physiological maturity (GS 5.4). Plant height was measured at 28, 42, 56, 70, 84, days after planting (DAP). Before budding it was done from the base of the above the soil stem to the tip of the tallest leave), but after budding, it was measured to the tip of the flower bud. The total number of leaves plant^{-1} was counted after the end of the vegetative stage when budding started (growth stage 3.1). Plants in both glasshouses were sampled at the budding, full flowering and physiological maturity stages to determine the leaf area and dry mass after being oven dried for 48hrs at 80^{o}C. Number of flower stems (NFS) and pods plant^{-1} (NPP) were recorded at final harvest (physiological maturity) stage and pods dry mass (PDM) plant^{-1} were also obtained after oven drying the samples for 48hrs at 80^{o}C. Formulae described by Paine *et al*. (2012) were adopted to calculate the following plant growth parameters for different genotypes and temperature regimes. Plant growth rate (PGR) from planting date to budding, from budding to flowering and from flowering to physiological maturity were calculated by dividing difference between the dry mass at beginning(DM1) and at end (DM2) of each growth interval with the number of days needed for the different growth intervals. Relative growth rates (RGR) were calculated by dividing each PGR with DM1 while net assimilation rates (NAR) were calculated by dividing PGR with leaf area at beginning of each growth interval (LA1). Relative growth rate (RGR and net assimilation rate (NAR) were only calculated from budding to flowering and from flowering to physiological maturity because plant did not have any leaf area at planting and seed mass at planting are so small that RGR values would be unrealistic. Because of large differences between plants only mean values and not individual replication values were used. DAP, Growing Degree Days (GDD) and Photo thermal Unit (PTU) at budding, flowering and physiological maturing stages were correlated with LA, DM, NPP and PDM at budding, flowering and physiological maturing stages to determine whether there were relationships between the variables.

An appropriate analysis of variance (ANOVA) was performed, using Statistica software, version 12®. The Bonferroni test's least significant difference (LSD) values were calculated at the 5% probability level to compare treatment means.

3.1 Results and Discussion

3.1 Plant height

As expected all genotypes showed a significant increase in plant height with time (days after planting) and heights of about 150 cm were achieved after 84 days when plants were already in the pod filling stage (Figure 1). Genotypes responded differently to temperature treatments. Genotypes, 43Y85,

158 44Y84, Hyola 575 and Hyola 50 showed little response to the different temperature treatments (10/15^{o}C
159 and 15/20^{o}C), but all other genotypes showed a significant increase in plant height with an increase in
160 night/day temperature from 10/15^{o}C and 15/20^{o}C. Differences in plant height were in most cases
161 shown from 56 DAP onwards and largest differences were found with early and mid-early maturing
162 genotypes Hyola571 and AGAMAX and 43Y85 because these genotypes were already at the budding
163 stage, which is characterized by rapid stem elongation. But because early maturing genotypes such as
164 43Y85 and Hyola 575 did not show a large response to temperature, no conclusion can be drawn with
165 regard to the response for different maturity groups.

166 These results are in agreement with the findings of Qaderi *et al*. (2006) who reported that higher
167 temperatures increased height of canola plants, but Dong *at al*. (2011) reported that higher
168 temperatures in combination with short day lengths reduced stem height in rice crop in eastern China.

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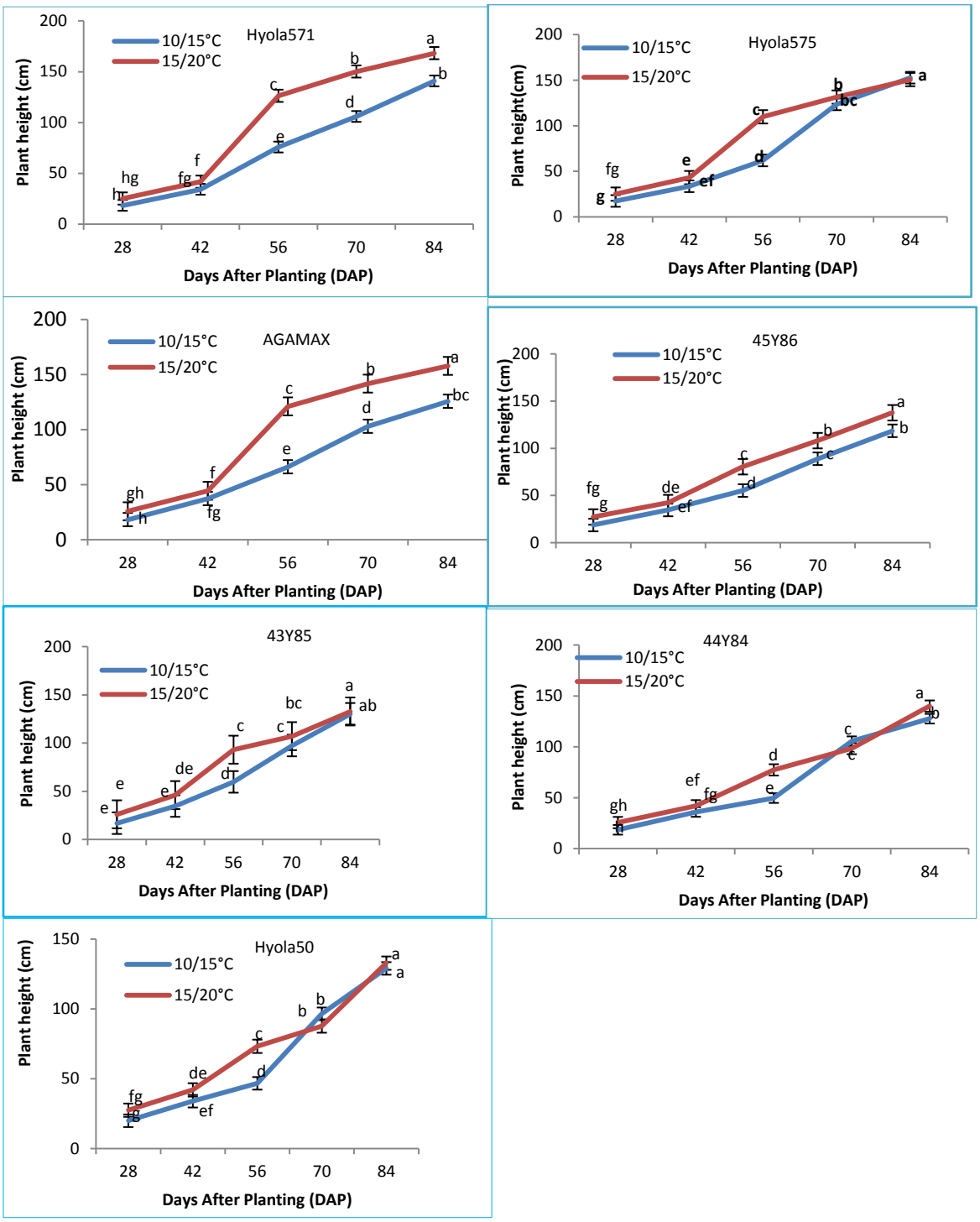

Figure 1 Plant heights (cm) of different canola genotypes, measured at 28, 42, 56, 70 and 84 days after planting (DAP), in response to night/ day temperatures of 10/15°C and 15/20°C. *Values with the same alphabetical lettering do not differ significantly at P=0.05*

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183 *3.2 Number of leaves*

184 The total number of leaves ranged from 10 to 14 per plant. Genotypes did differ with regard to the
185 number of leaves produced when subjected to different growing temperatures (Figure 2). In general
186 genotypes tend to produce more leaves at the higher night/day temperature (15/20^{o}C), but with the
187 exception of the early maturing cultivar 43Y85 and the mid maturing cultivar 45Y86. At the lower
188 temperature regime (10/15^{o}C), early maturing genotypes Hyola 571 and Hyola 575, produced less leaves
189 than other genotypes. At the higher temperature regime of 15/20^{o}C, Hyola 571, Hyola 575 and AGAMAX
190 produces less leaves than genotypes 43Y85, 44Y84 and 45Y86. Hyola 571 and Hyola 575 also produce
191 less leaves than Hyola 50. Hyola 50 on the other hand, produces less leaves than early maturing 43Y85
192 and mid-early 44Y84 and mid maturing 45Y86. Because genotypes 43Y85, 44Y84 and 44Y85 tend to
193 produce the largest number of leaves at especially the higher temperature regime, results suggested
194 that number of leaves produced before budding stage when stem elongation started, may to a larger
195 degree be related to the cultivar origin than maturity grouping. These results are in contrast to the
196 findings of Slauenwhite and Qaderi (2013) who found no significant difference in leaf numbers plant^{-1}
197 among four canola genotypes; 46A76, 45H72, 45H24 and 45H21 grown at day/night temperature
198 regimes of 24/20^{o}C and 30/26^{o}C, though we don't know the maturity grouping of these genotypes.
199 These authors also reported that higher temperature reduced leaf number plant^{-1}. This contrasting
200 results may indicate that the lowest temperature regime of 24/20^{o}C used in their study were already
201 above the optimum for leaf initiation in canola.

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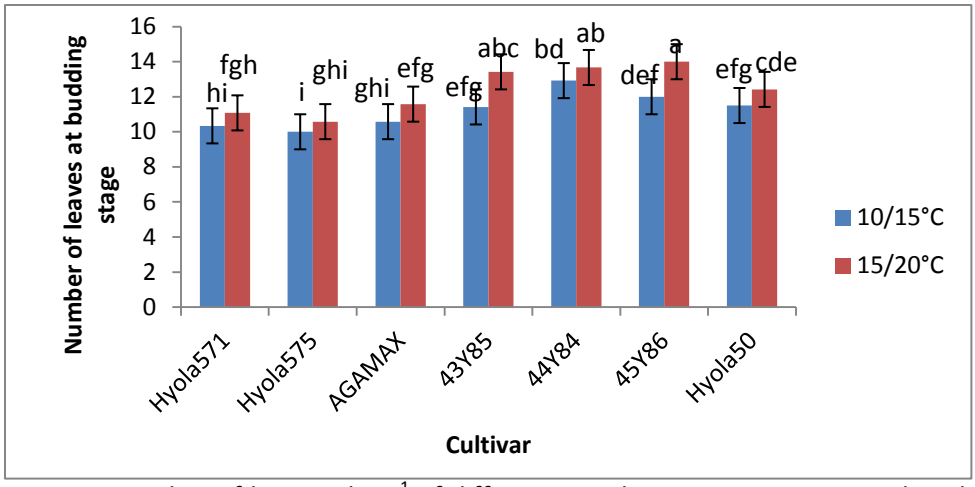

Figure 2 Number of leaves plant^{-1} of different canola genotypes, measured at the beginning of budding (growth stage 3.1) in response to night/ day temperatures of 10/15^{o}C and 15/20^{o}C. *Values with the same alphabetical lettering do not differ significantly at P=0.05*

3.3 Leaf area

In general leaf area plant^{-1} increased from budding stage to reach a maximum at flowering, where-after it started to decrease. At all sampling stages, leaf area plant^{-1} (cm^{3}) was affected by temperature regime. On average, larger leaf areas were produced at the lower night/day temperature of 10/15^{o}C during flowering and final harvesting stage (Figure 3), but not so at budding stage. This tendency indicates an increase in leaf senescence at the higher temperature regime. Different canola genotypes however responded differently to the increase in temperature from 10/15^{o}C to 15/20^{o}C.

At budding stage only Hyola 575 and Hyola 50 showed a significant increase in leaf area plant^{-1} with an increase in temperature (Figure 3), resulting in significant larger leaf areas plant^{-1} compared to early maturing Hyola 571 at the higher temperature regime (15/20^{o}C), but not so at the lower temperature regime (10/15^{o}C). Although Hyola 571 showed on average the smallest leaf area plant^{-1} at budding stage, no clear trend due to maturity grouping was shown.

At flowering stage, significant decreases in leaf area plant^{-1} due to the increase in temperature from 10/15^{o}C to 15/20^{o}C were shown for genotypes, Hyola 571, AGAMAX and 45Y86, while the reverse was the case for 43Y85 (Figure 3). Cultivar AGAMAX produced the largest leaf area plant^{-1} at the low temperature regime (10/15^{o}C), while at the higher temperature regime (15/20^{o}C), the leaf area of 43Y85 plants at flowering were significantly larger than other genotypes. On average, early maturing genotypes Hyola 571 and Hyola 575 tend to produce the smallest leaf area plant^{-1}.

During the final harvest at growth stage 5.4, leaf area plant^{-1} with the exception of the early maturing cultivar Hyola 571 tend to decrease with an increase in temperature regime, but differences were not significant (Figure 3). No significant differences were recorded between genotypes at the 10/15^{o}C temperature regime, but at the higher temperature regime (15/20^{o}C), Hyola 575 showed a significantly smaller leaf area compared to 44Y84. In general mid-early maturing genotypes tend to have larger leaf areas than early maturing or mid maturing genotypes at this stage.

These results did not show clear evidence that genotypes of the same maturity group followed similar pattern with regard to their leaf area development at any of the sampling times, but in general mid-early maturing genotypes tend to produce the largest leaf area plant^{-1}. Higher night/day temperatures resulted in larger leaf areas at budding, but smaller leaf areas at flowering and especially during the final harvesting at growth stage 5.4. Schwabe (1957) and Humphries (1969) also showed that leaf initiation and expansion rate during the early growth stage of seedlings are increased by higher temperatures. Rawson and Dunstone (1986) as well as Nanda *et al*., (1995) reported that temperature affects crop phenology and thus can change pattern of leaf area development by altering the source-sink relationship. They observed that before onset of flowering, leaves and stem were the main sites of assimilation, taking up to 46% and 41% of dry matter respectively, but at onset of pod filling, leaves as assimilated only 19% of dry matter produced.

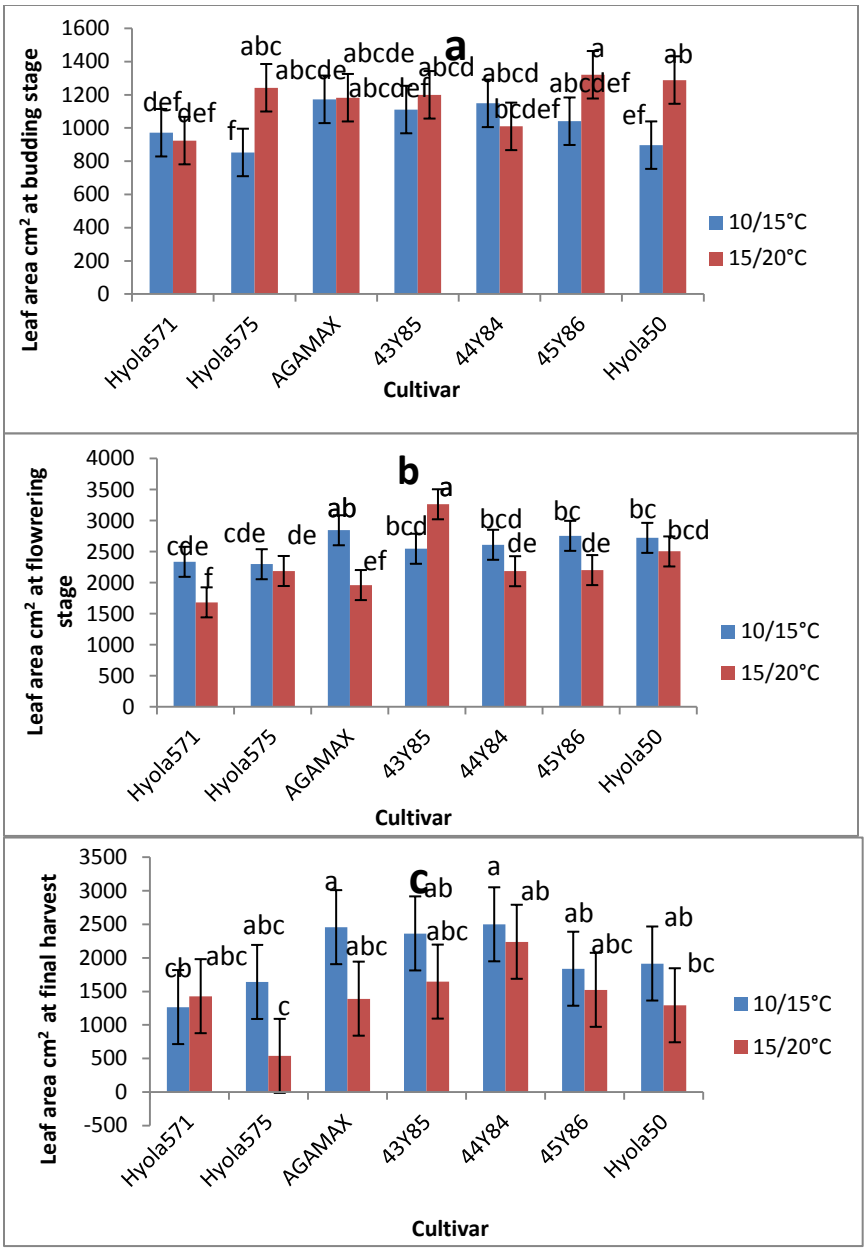

Figure 3 Leaf area plant^{-1} (cm2) of different canola genotypes , measured at (a)the beginning of budding (growth stage 3.1) (b) flowering and (c) during the final harvest at growth stage 5.4 in response to night/ day temperatures of 10/15^{o}C and 15/20^{o}C. *Values with the same alphabetical lettering do not differ significantly at P=0.05*

3.4 Dry mass

Above ground dry mass plant^{-1} increased with time for all genotypes, but was affected by both cultivar and temperature (Figure 4).

At budding stage (growth stage 3.1), a higher dry mass plant^{-1} was generally recorded for plants grown at the higher temperature regime of 15/20^{o}C, but differences were only significant for the genotypes Hyola 575, Hyola 50 and 45Y86.

At flowering, above ground dry mass was, with the exception of the early maturing cultivar 43Y85, in all genotypes significantly reduced when grown at the higher temperature regime of 15/20^{o}C. With the exception of Hyola 571 which produced significantly less dry mass than 43Y85, no differences were recorded between genotypes growing in the 15/20^{o}C glasshouse. In the cooler glasshouse (10/15^{o}C), the highest dry mass at flowering was produced by early and mid-early genotypes Hyola 571 and AGAMAX.

At final harvest (FH), no significant interaction between growing temperature regime and cultivar was recorded with dry mass of all genotypes reduced at the higher temperature regime of 15/20^{o}C (Figure 4). AGAMAX and 43Y85 recorded significantly higher dry mass than all genotypes in the 15/20^{o}C, but only higher than Hyola 571 in the 10/15^{o}C glasshouse. In general early and mid-early maturing types (Hyola 575,Hyola 571, AGAMAX and 43Y85) showed larger reductions in dry mass of 41.31%, 34.69%, 39.65% and 40.65% respectively in the higher temperature glasshouse, while mid and mid to mid-early maturing types, 45Y86, Hyola 50 and 44Y84 showed reductions of 18.81%, 30.40% 28.41% respectively.

In general, canola plants at 15/20^{o}C temperature regime accumulated more above ground dry mass at budding stage and more so for late maturing genotypes than at 10/15^{o}C temperature regime. It seems that the trait(s) for lateness enabled late maturing genotypes to produce more leaves by reducing the time between appearances of successive leaves. Therefore more leaves and leaf area recorded by late maturing genotypes at higher temperature regime during budding stage as shown in figures 2 and 3 might be responsible for more above ground dry mass accumulated at budding stage. Canola has been reported to partition more dry mass to leave in the early growth stage than wheat, barley and sorghum (Rood *et al*., 1984, Deligios *et al*., 2013). While Faraji *et al*., (2009) and Faraji (2014) showed significant positive correlations between leave number before flowering and dry mass as well as final grain yield. Morrison *et al*. (1991) also reported that crops produce leaves at slower rate when exposed to low temperature. For this reason, the higher dry mass accumulated at the 15/20^{o}C temperature regime compared to 10/15^{o}C temperature regime during growth stage, could be because leaves were produced at faster rate.

Results from this study are in agreement with earlier studies (Qaderi *et al*. 2006, Gou, *et al*., 2010, Nordli *et al*., 2011) reporting an increase in dry matter production during earlier growth stages with higher

288 temperatures, but a decrease in total dry mass production due to more rapid crop development and a
289 shortened growth period.

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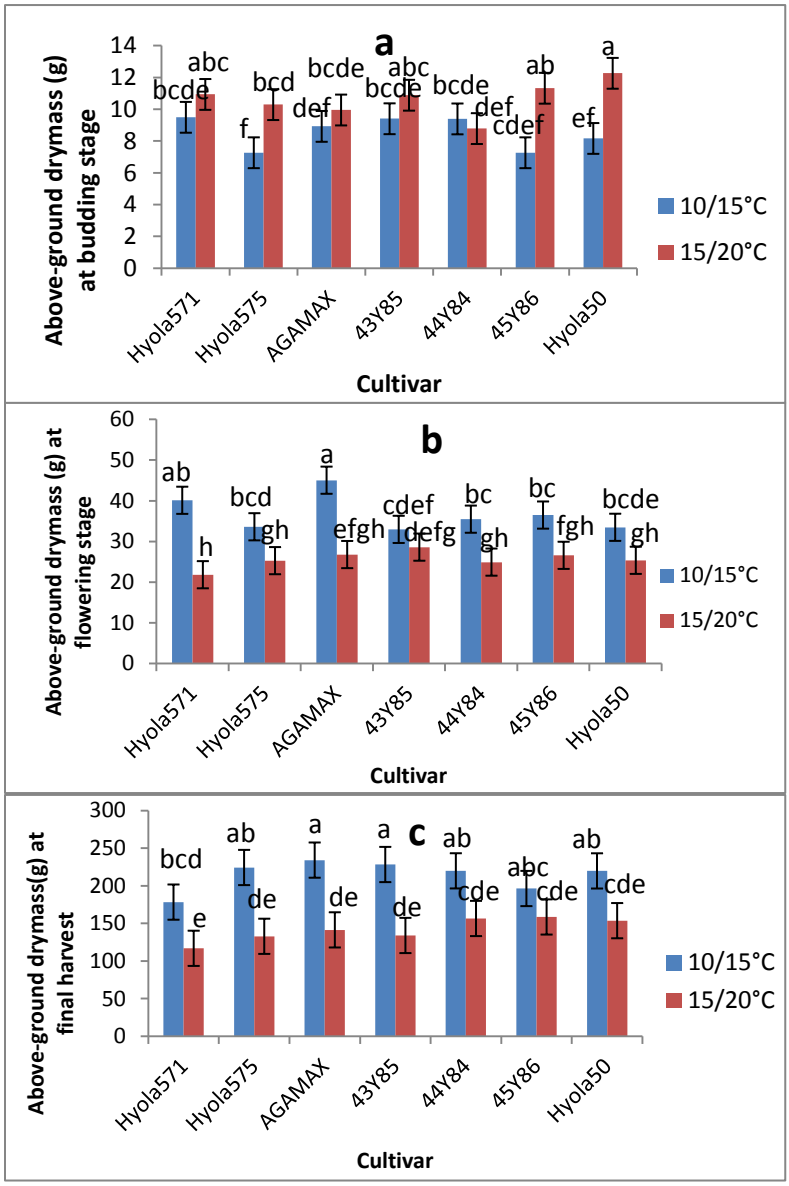

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295 **Figure 4** Dry mass plant^{-1} (g) of different canola genotypes , measured at (a)the beginning of budding
296 (growth stage 3.1) (b) flowering and (c) during the final harvest at growth stage 5.4 in response to
297 night/ day temperatures of 10/15°C and 15/20°C. *Values with same alphabetical lettering do not differ*
298 *significantly at P=0.05*

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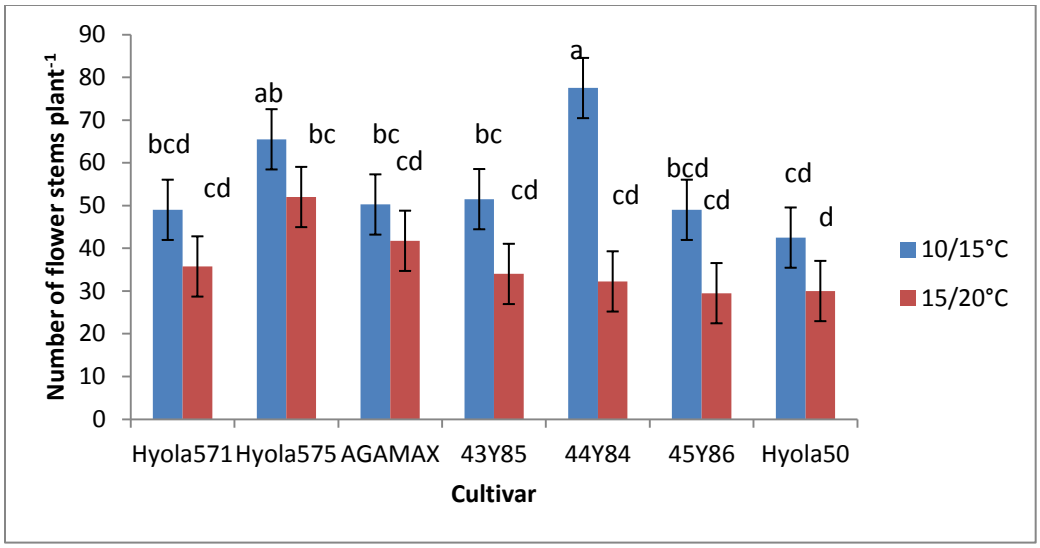
3.4 Number of flower stems

Although all genotypes showed a decrease in the number of flower stems when grown at a lower temperature (10/15^{o}C) instead of 15/20^{o}C, differences were only significant for cultivar 44Y84 (Figure 5). With the exception of Hyola 575, cultivar 44Y84 produced significantly more flower stems compared to other genotypes at the lower temperature regime of 10/15^{o}C, but at the higher temperature regime (15/20^{o}C) no significant differences were recorded between genotypes tested, except for Hola575 and Hola 50.

The reduction in number of flower stems recorded in the higher temperature regime could be attributed to the fact that the higher temperature regime of 15/20^{o}C reduced the duration of different growth stages, so that plants have less time to develop flower stems. Similar results were reported by Kutcher *et al*. (2010) who found that high temperatures during vegetative growth reduced number of flowers produced per plant.

Except for the already mentioned difference between 44Y84 and others genotypes at the lower temperature regime, the number of flower stems produced by different genotypes did not show any relationship with their maturity grouping as early and later maturing genotypes produced the same number of flower stems.



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321 **Figure 5** Flower stems plant^{-1} of different canola genotypes, measured during the final harvest at growth
322 stage 5.4 in response to night/ day temperatures of 10/15^{o}C and 15/20^{o}C. *Values with the same*
323 *alphabetical lettering do not differ significantly at P=0.05*

324 3.*6 Number of pods*

325 The number of pods plant^{-1} ranged from 841 to 1483. Genotypes differed with respect to number of
326 pods plant^{-1} when grown at different temperature regimes (Figure 6). With the exception of Hyola 50
327 and 44Y84, all genotypes produced significantly less pods plant^{-1} at the higher temperature regime of
328 15/20^{o}C compare to 10/15^{o}C. However, differences between genotypes at both temperature regimes
329 (10/15^{o}C and 15/20^{o}C) were not significant. With exception of 45Y86, later maturing genotypes (44Y84
330 and Hyola 50) showed less reduction in the number of pods per plant in the higher temperature regime
331 than early and mid-early maturing types.

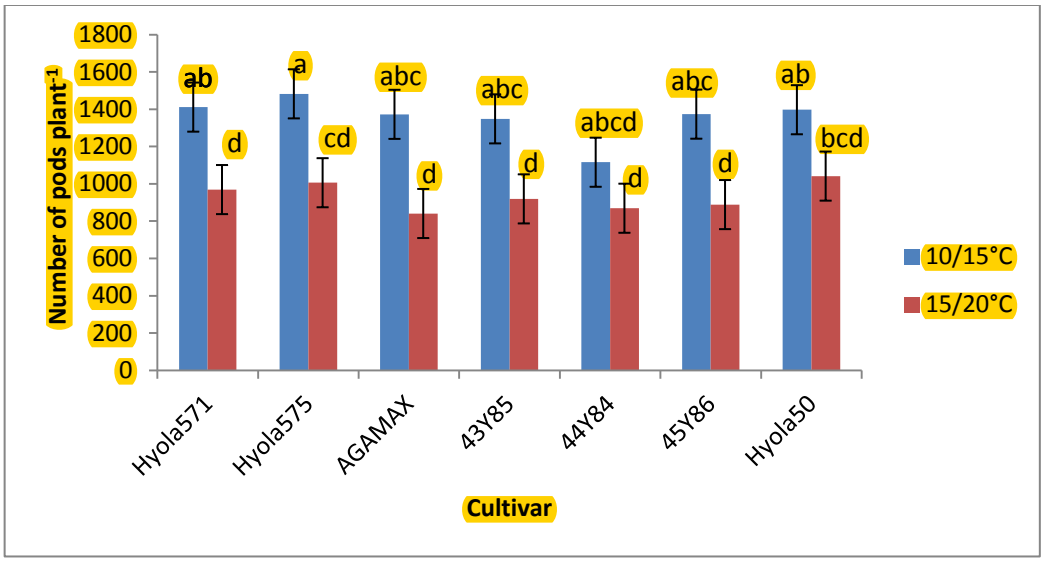
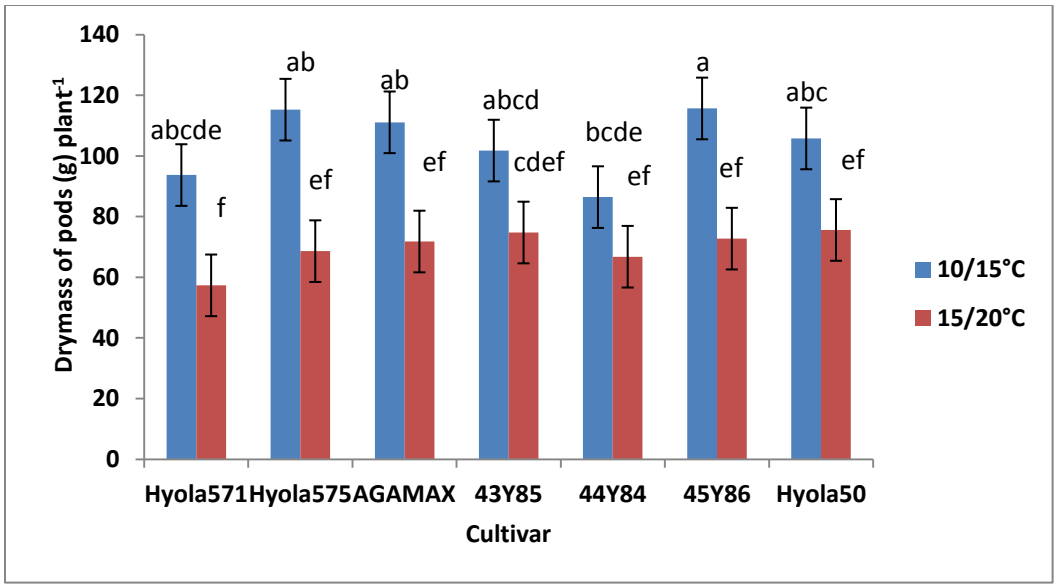


Figure 6 Effect of temperature on number of pods plant^{-1} of different canola genotypes, measured during the final harvest at growth stage 5.4 in response to night/ day temperatures of 10/15^{o}C and 15/20^{o}C. Values with the same alphabetical lettering do not differ significantly at P=0.05

3.7 Dry mass of pods

With exception of 44Y84 and 43Y85, all genotypes showed a significant reduction in dry mass of pods plant^{-1} at the 15/20^{o}C temperature regime compared to the 10/15^{o}C temperature regime (Figure 7). Dry mass of pods varied between about 80 and 116 g plant^{-1} at the lower day/night temperature of 10/15^{o}C and differences between genotypes were not significant except for the difference between 45Y86 and 44Y84,. No significant differences between genotypes were recorded at the 15/20^{o}C temperature regime and the pod dry mass plant^{-1} varied between about 58 and 72 g. Early maturing Hyola 575 and Hyola 571 showed higher pods dry mass reductions than mid-maturing Hyola 50 with an increase in temperature. In contrast to this, early maturing 43Y85 showed less response than mid-maturing 45Y86, indicating genetic differences between early maturing genotypes.

The reduced duration of growth stages, increased rate of respiratory break down of accumulated dry mass and accelerated leaf senescence due to the higher temperature might be the reason for the reduced pod dry mass at the 15/20^{o}C regime. Kutcher *et al*. (2010) reported that increased mean temperature during vegetative development reduced the number of seeds and size of seed per flower and consequently resulted in seed yield reduction, the view also shared by findings of Morrison and Stewart (2002).



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354 **Figure 7** Pod dry mass plant^{-1} of different canola genotypes, measured during the final harvest at
355 growth stage 5.4 in response to night/ day temperatures of 10/15^{o}C and 15/20^{o}C. Values with the same
356 alphabetical lettering do not differ significantly at P=0.

357 **3.8 Effect of temperature on plant growth rate (PGR), relative growth rate (RGR) and net assimilation**
358 **rate (NAR) of canola genotypes at budding, flowering and physiological maturity stages**

359 *3.8.1 Plant growth rate (PGR).*

360 Plant growth rate (PGR) increased progressively from planting to budding and from flowering to
361 physiological maturity at both temperature regimes (Table 1). On average a PGR of 0.2414 g plant^{-1} day^{-1}
362 was recorded from planting to budding compared to 1.4452 g plant^{-1} day^{-1} and 2.0295 g plant^{-1} day^{-1}
363 measured from budding to flowering and from flowering to physiological maturity. However, at each
364 sampling stage, PGR differ as a result of both temperature and genotypes tested. From planting to
365 budding, all genotypes showed a higher PGR at the 15/20^{o}C temperature regime compared to the
366 10/15^{o}C temperature regime, but from budding to flowering and flowering to physiological maturity a
367 higher PGR was measured for all genotypes at the lower (10/15^{o}C) temperature regime compared to the
368 15/20^{o}C temperature regime. Genotypes also differed at both temperature regimes with respect to PGR.
369 From planting to budding a PGR of 0.2752 g plant^{-1} day^{-1} was measured on average for the higher
370 temperature regime of 15/20^{o}C compared to 0.2075 gplant^{-1} day^{-1} for the lower temperature regime
371 (10/15^{o}C). At the 15/20^{o}C temperature regime, 45Y86 showed highest PGR, while Hyola 571 recorded
372 the highest PGR at the 10/15^{o}C temperature regime from planting to budding. From budding to
373 flowering stage, a higher PGR of 1.6124 g plant^{-1} day^{-1} were recorded on average by genotypes at the

374 10/15^{o}C temperature regime compared to 1.2780 g plant^{-1} day^{-1} on average at the 15/20^{o}C temperature
375 regime. At the 10/15^{o}C temperature regime, AGAMAX recorded highest PGR, whereas at 15/20^{o}C
376 temperature regime 43Y86 showed the highest PGR. Genotypes also showed a higher PGR at the lower
377 temperature regime of 10/15^{o}c compared to higher temperature regime (15/20^{o}C) from flowering to
378 physiological maturity. At the 10/15^{o}C temperature regime genotypes grew at 2.2008 g plant^{-1} day^{-1},
379 while at the 15/20^{o}C temperature genotypes grew at 1.8584 g plant^{-1} day^{-1}. Cultivar, 43Y85 showed the
380 highest PGR at 10/15^{o}C, whereas at 15/20^{o}C 44Y84 recorded the highest PGR from flowering to
381 physiological maturity.

382 The increase in PGR from planting to physiological maturity indicated that PGR for all genotypes
383 followed the normal growth rate curve, which usually increases as plant growth duration increase.
384 Similar results have been reported on soybean, barley and maize (Garmash 2005, Liu *et al*. 2006,
385 Thomas *et al*. 2010, Tsimba *et al*. 2013). Increased PGR from planting to budding at 15/20^{o}C
386 temperature regime and decrease from budding to flowering and flowering to physiological maturity
387 suggest that increasing the mean night/day temperature from 12.5^{o}C to 17.5^{o}C increased PGR during
388 the vegetative growth stage (planting to budding) by increasing the rate of leaf appearance and
389 expansion, but as growth progress the increase in temperature decreased PGR by increasing the rate of
390 leaf senescence and respiratory break down of photosynthates (Munier-Jolain et al. 2008, Tsimba et al.
391 20011, Tacarindua et al. 2012). Although genotypes differed in growth rate, it did not show any
392 relationship with their maturity grouping.

393 *3.8.2 Relative growth rate (RGR).*

394 A higher RGR of 0.1528 g g^{-1} day^{-1} was shown on average from budding to flowering compared to a
395 lower RGR of 0.0669 g g^{-1} day^{-1} from flowering to physiological maturity (Table 1). From budding to
396 flowering, RGR was higher at the 10/15^{o}C temperature regime (0.1840 g g^{-1} day^{-1}) than at the 15/20^{o}C
397 temperature regime (0.1215 g g^{-1} day^{-1}) , while from flowering to physiological maturity a higher RGR of
398 0.0727 g g^{-1} day^{-1} was recorded by genotypes at the 15/20^{o}C temperature regime compare to a PGR of
399 0.0610 g g^{-1} day^{-1} at the 10/15^{o}C temperature regime . AGAMAX showed the highest RGR at the 10/15^{o}C
400 temperature regime, whereas at 15/20^{o}C temperature regime 44Y84 recorded the highest RGR from
401 budding to flowering stage. From flowering to physiological maturity 43Y85 showed the highest RGR at
402 the 10/15^{o}C temperature, while AGAMAX showed the highest RGR at 15/20^{o}C.

The higher RGR observed from budding to flowering compared to flowering to physiological maturity could be attributed to the quantity of the dry mass at the beginning of the growth stage (DM1). The RGR from budding to flowering was calculated by dividing PGR with dry mass at budding, while RGR from flowering to physiological maturity was calculated by dividing PGR with dry mass at flowering stage. The DM at flowering stage was higher than DM at budding stage, therefore as (DM1) increases RGR within any range of growth stages decreases. The same applies for differences between temperature regimes., dry mass at budding stage were higher at 15/20^{o}C temperature regime, so there was lower RGR from budding to flowering stage and vice-visa, while at flowering stage dry mass were higher at 10/15^{o}C temperature regime and lower RGR were observed from flowering to physiological maturity and vice-visa. Similar trends of RGR have been observed on wheat, soybean and maize (Victor *et al*. 2006, Federick *et al*. 2013, Tacarindua *et al*. 2013, Tsimba *et al*. 2013) and therefore show that the efficacy of crops to accumulate dry mass decreases towards the end of the growing season . Differences between genotypes did not show any relationship with maturity grouping.

3.8.3 Net assimilation rate (NAR).

A higher NAR of 0.00136 g cm^{-1} day^{-1} was recorded by genotypes at both temperature regimes from budding to flowering when compared to the 0.00083 g cm^{-1} day^{-1} from flowering to physiological maturity. From budding to flowering genotypes recorded higher NAR of 0.00161 g cm^{-1} day^{-1} at 10/15^{o}C temperature regime compared to the 0.00111 g cm^{-1} day^{-1} at the 15/20^{o}C temperature regime. From flowering to physiological maturity there was no difference between NAR at different temperature regimes. Genotypes of the same maturity groups did not show similar NAR values at different sampling stage or temperature regimes

At the 10/15^{o}C temperature regime Hyola571 recorded the highest NAR from budding to flowering, while 43Y85 showed the highest NAR at 15/20^{o}C. From flowering to physiological maturity there were no difference between temperature regimes but genotypes did differ. At the 10/15^{o}C temperature regime Hyola 575 showed the highest NAR, whereas all genotypes, with the exception of 43Y85, showed NAR values of 0008-0009 g cm^{-1} day^{-1} at the 15/20^{o}C temperature regime.

The higher NAR recorded from budding to flowering stage than from flowering to physiological maturity can be attributed to lower leaf area at budding stage (LA1), which was used as the divisor of the PGR from budding to flowering and higher leaf area at flowering (LA1) which was use as divisor of PGR from flowering to physiological maturity. These results agreed with findings of Gaetan et al. (2008) and John and Kim (2014) who also showed that NAR and photosynthetic efficiency of plants decrease towards the end of the growing season.

436 **Table 1** Effect of temperature on plant growth rate (PGR) (g plant^{-1}day^{-1}), relative growth rate of plants
437 (RGR)(g g^{-1} day^{-1}) and net assimilation rate of plants (NAR) (g cm^{-2}day^{-1}) of the different canola
438 genotypes determined for the periods: Planting to budding; Budding to flowering and from flowering to
439 physiological maturity.

		Planting to budding	Budding to flowering			Flowering to physiological maturity		
Temp	**Cultivar**	**PGR**	**PGR**	**RGR**	**NAR**	**PGR**	**RGR**	**NAR**
10/15^{o}C	Hyola571	0.2315	2.04	0.215	0.0021	1.7377	0.0433	0.0007
	Hyola575	0.1773	1.645	0.2269	0.0019	2.414	0.0719	0.0011
	AGAMAX	0.2178	2.1241	0.2379	0.0018	2.3058	0.0512	0.0008
	43Y85	0.2176	1.3847	0.1472	0.0013	2.5697	0.078	0.001
	44Y84	0.2136	1.303	0.1385	0.0013	2.1754	0.0613	0.0008
	45Y86	0.209	1.6135	0.1785	0.0016	1.8589	0.051	0.0007
	Hyola50	0.1857	1.1763	0.144	0.0013	2.3432	0.07	0.0007
10/15^{o}Cmean		**0.2075**	**1.6124**	**0.184**	**0.00161**	**2.2008**	**0.061**	**0.00083**
15/20^{o}C	Hyola571	0.2957	1.086	0.0993	0.0012	1.5571	0.0714	0.0009
	Hyola575	0.2765	1.0736	0.105	0.0009	1.886	0.0747	0.0008
	AGAMAX	0.2692	1.3177	0.1323	0.0011	1.9666	0.0735	0.0009
	43Y85	0.2656	1.6456	0.1511	0.0014	1.8259	0.0639	0.0006
	44Y84	0.2144	1.3425	0.1527	0.0013	1.9567	0.0786	0.0009
	45Y86	0.3062	1.1723	0.1035	0.009	1.898	0.0714	0.0009
	Hyola50	0.299	1.308	0.1067	0.001	1.9185	0.0757	0.0008
15/20^{o}Cmean		**0.2752**	**1.278**	**0.1215**	**0.00111**	**1.8584**	**0.0727**	**0.00083**
GSmean		**0.2414**	**1.4452**	**0.1528**	**0.00136**	**2.0295**	**0.0669**	**0.00083**

440 GSmean (growth stage mean)

4.0 Conclusions

The study demonstrated that an increase in night/day temperature from 10/15^{o}C to 15/20^{o}C resulted in an increase in plant height, leaf number at budding stage, leaf area at budding, plant growth rate from planting to budding stage, but reduces plant growth rate from budding to physiological maturity, net assimilation rate from budding to flowering stage, leaf area at flowering and physiological maturity stages, as well as the number of flower stems, number of pods plant^{-1}, above ground l dry mass at flowering and physiological maturity stages and pod dry mass at physiological maturity stage by 22.24% to 40.35%.

It also showed that on average, later maturing (mid-maturing) genotypes produced more leaves, leaf area at budding, flowering and physiological maturity stages, as well as above ground dry mass at budding stage compared to early maturing genotypes. However, they produced less flower stems and pods plant^{-1}. At physiological maturity, early maturing genotypes (Hyola 575 and Hyola 571) showed the highest reduction in pods dry mass of 40.35% and 38.28% respectively with an increase in temperature to 15/20^{o}C. Surprisingly, the early maturing 43Y85 shared most of morphological characteristics of later maturing (mid- maturing) group, instead of those of early and mid-early types, indicating that the response of different genotypes to an increase in temperature might to a large degree be related to their genetics (genotype) and not to their maturity grouping.

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