

**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°C and 15/20°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°C to 15/20°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).

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

48 In general development of an annual crop from emergence to maturity can be divided into three major
49 phenological developmental phases: from emergence to flower buds initiation-vegetative development,
50 from floral buds initiation to anthesis-reproductive development and from anthesis to physiological
51 maturity -seed filling (Craufurd and Qi, 2001, Ritchie, 1991, Siebert and Ewert 2012). However, canola
52 developmental stages can be divided into six phases according to Harper and Berkenkamp (1975): Phase
53 0-Pre-emergence, Phase 1-Seedling, Phase 2-Rosette, Phase 3-stem elongation, Phase 4-flowering,
54 Phase 5-Seed maturation. Under climate change scenario, increase in both the mean and extremes of
55 temperature are expected for many parts of the world (IPCC 2001). These changes can impact largely
56 on the growth and phenological development of crops. Temperature and to less extent photoperiod
57 have been reported to be major environmental factors that determine the timing and duration of each
58 of the phenological phases in the physiological development of crops (Roberts *et al.* 1993). Many models
59 have been developed to explain the phenological phases that take place during growth and
60 development of crops (Alocija and Ritchie 1991, Matthews and Hunts 1994), while the physiological
61 mechanisms that govern the transition from one phenophase to another are strongly influenced by
62 environmental factors and have been described using photothermal models (Summerfield *et al.* 1991).

63 Photoperiod has been reported to be principally factor that determines the time of floral initiation and
64 hence onset of anthesis in many crop species (Burtero *et al.* 1999). Photoperiod, for example affects
65 floral development of rice (*Oryza sativa* L.) (Coolhaas and Wormer 1953), caryopteris (Piringer *et al.*
66 1963), wheat(*Triticum aestivum* L.) (Slafer and Rawson 1994), barley (*Hordeum vulgare* L.) (Kernich *et*
67 *al.* 1996) and quinoa (*Chenopodium quinoa willd*) (Burtero *et al.* 1999). However, it is not clear whether

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

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

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

103 **1. MATERIALS AND METHODS**

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

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

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

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

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

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

153 **3.1 Results and Discussion**

154 *3.1 Plant height*

155 As expected all genotypes showed a significant increase in plant height with time (days after planting)
156 and heights of about 150 cm were achieved after 84 days when plants were already in the pod filling
157 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°C
159 and 15/20°C), but all other genotypes showed a significant increase in plant height with an increase in
160 night/day temperature from 10/15°C and 15/20°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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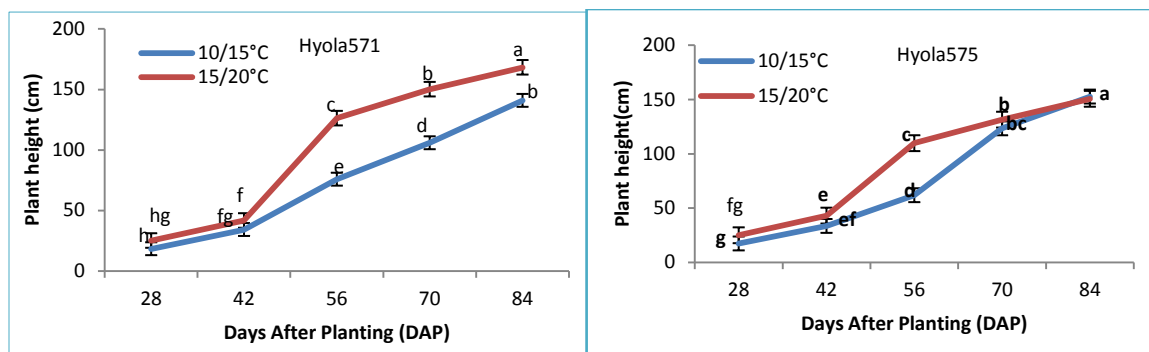
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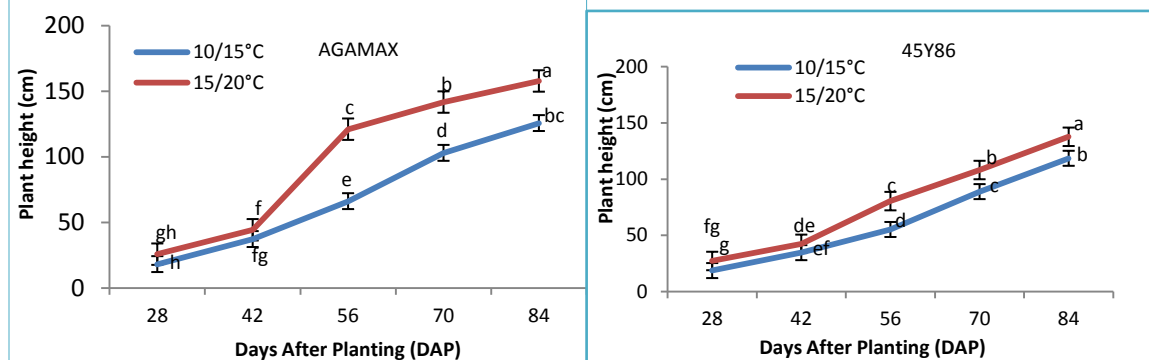
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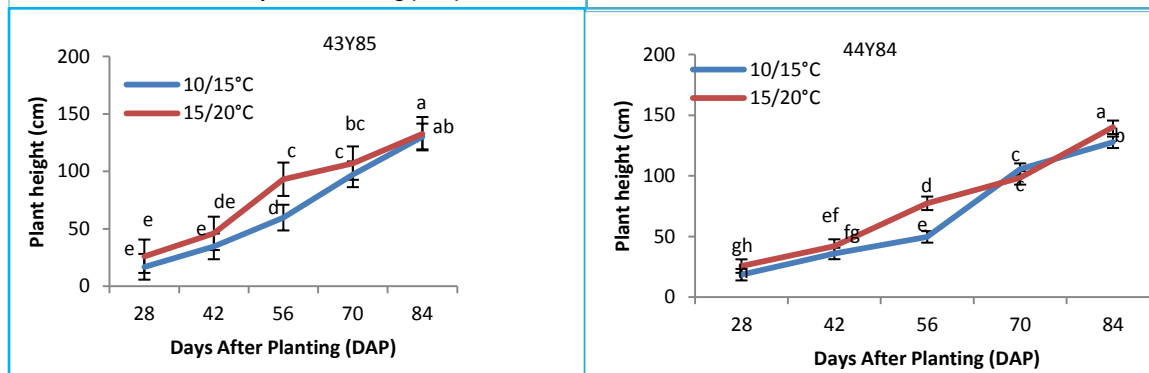
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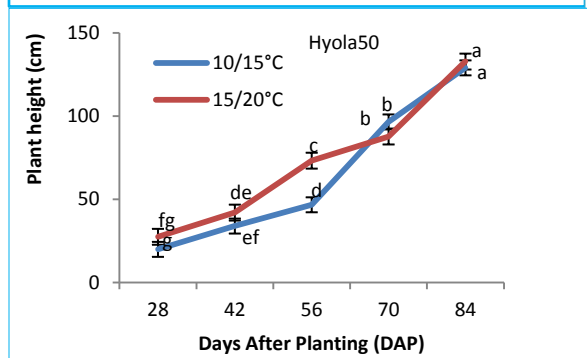
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178 **Figure 1** Plant heights (cm) of different canola genotypes, measured at 28, 42, 56, 70 and 84 days after planting
 179 (DAP), in response to night/ day temperatures of 10/15°C and 15/20°C. Values with the same alphabetical lettering
 180 do 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°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°C), early maturing genotypes Hyola 571 and Hyola 575, produced less leaves
189 than other genotypes. At the higher temperature regime of 15/20°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°C and 30/26°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°C used in their study were already
201 above the optimum for leaf initiation in canola.

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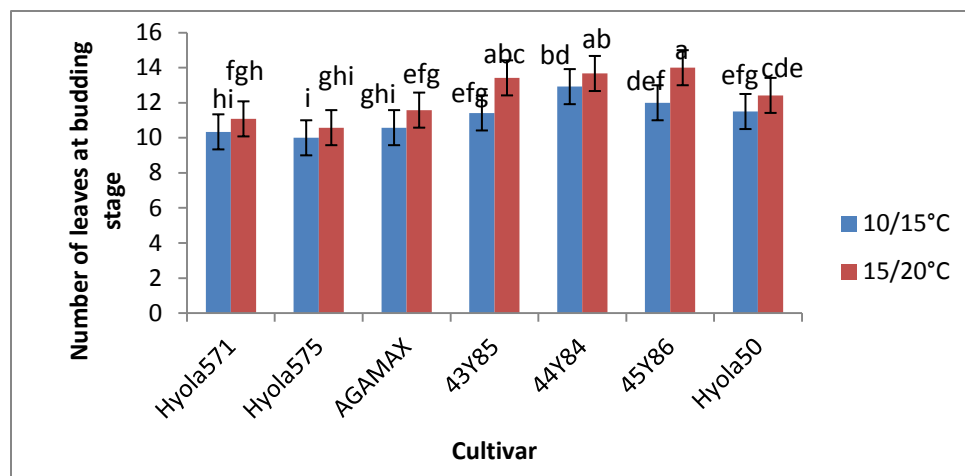
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209 Figure 2 Number of leaves plant⁻¹ of different canola genotypes, measured at the beginning of budding
 210 (growth stage 3.1) in response to night/ day temperatures of 10/15°C and 15/20°C. Values with the
 211 same alphabetical lettering do not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

212 **3.3 Leaf area**

213 In general leaf area plant⁻¹ increased from budding stage to reach a maximum at flowering, where-after
 214 it started to decrease. At all sampling stages, leaf area plant⁻¹ (cm³) was affected by temperature
 215 regime. On average, larger leaf areas were produced at the lower night/day temperature of 10/15°C
 216 during flowering and final harvesting stage (Figure 3), but not so at budding stage. This tendency
 217 indicates an increase in leaf senescence at the higher temperature regime. Different canola genotypes
 218 however responded differently to the increase in temperature from 10/15°C to 15/20°C.

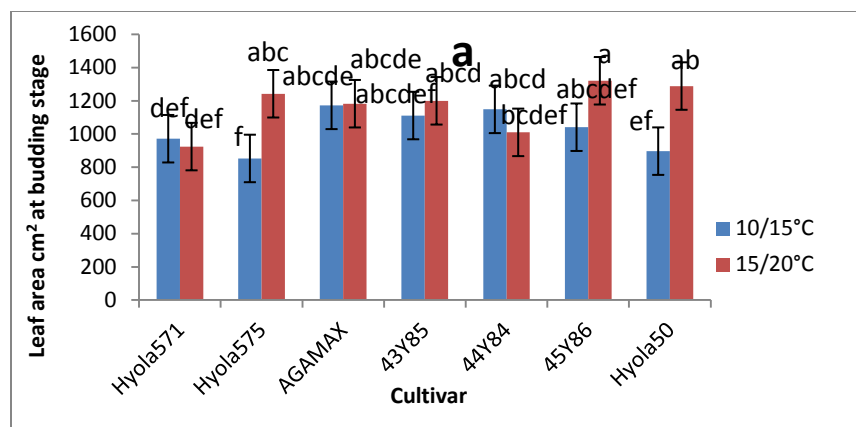
219 At budding stage only Hyola 575 and Hyola 50 showed a significant increase in leaf area plant⁻¹ with an
 220 increase in temperature (Figure 3), resulting in significant larger leaf areas plant⁻¹ compared to early
 221 maturing Hyola 571 at the higher temperature regime (15/20°C), but not so at the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

224 At flowering stage, significant decreases in leaf area plant⁻¹ due to the increase in temperature from
 225 10/15°C to 15/20°C were shown for genotypes, Hyola 571, AGAMAX and 45Y86, while the reverse was
 226 the case for 43Y85 (Figure 3). Cultivar AGAMAX produced the largest leaf area plant⁻¹ at the low
 227 temperature regime (10/15°C), while at the higher temperature regime (15/20°C), the leaf area of
 228 43Y85 plants at flowering were significantly larger than other genotypes. On average, early maturing
 229 genotypes Hyola 571 and Hyola 575 tend to produce the smallest leaf area plant⁻¹.

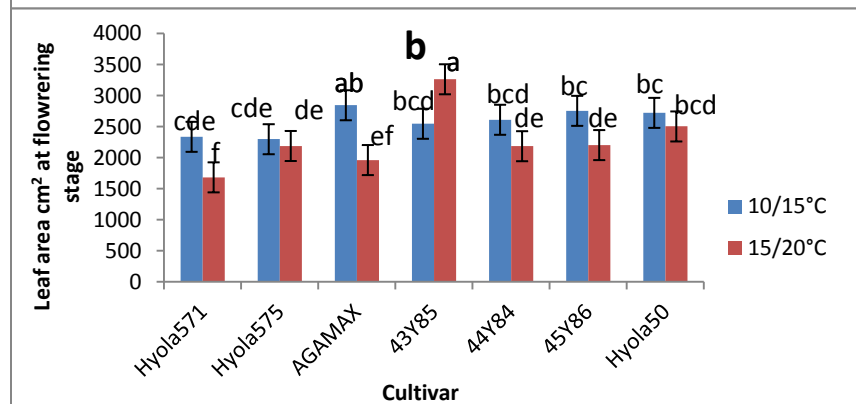
230 During the final harvest at growth stage 5.4, leaf area plant⁻¹ with the exception of the early maturing
231 cultivar Hyola 571 tend to decrease with an increase in temperature regime, but differences were not
232 significant (Figure 3). No significant differences were recorded between genotypes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

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

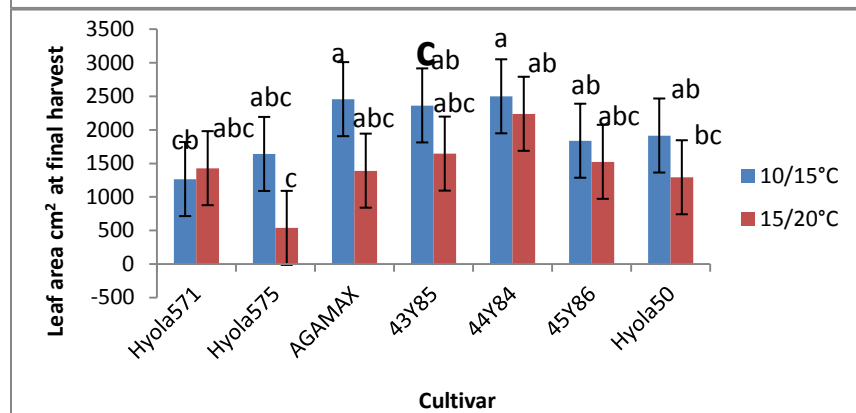
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251 **Figure 3** Leaf area plant⁻¹ (cm²) of different canola genotypes , measured at (a)the beginning of
 252 budding (growth stage 3.1) (b) flowering and (c) during the final harvest at growth stage 5.4 in
 253 response to night/ day temperatures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

255 **3.4 Dry mass**

256 Above ground dry mass plant⁻¹ increased with time for all genotypes, but was affected by both cultivar
 257 and temperature (Figure 4).

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

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

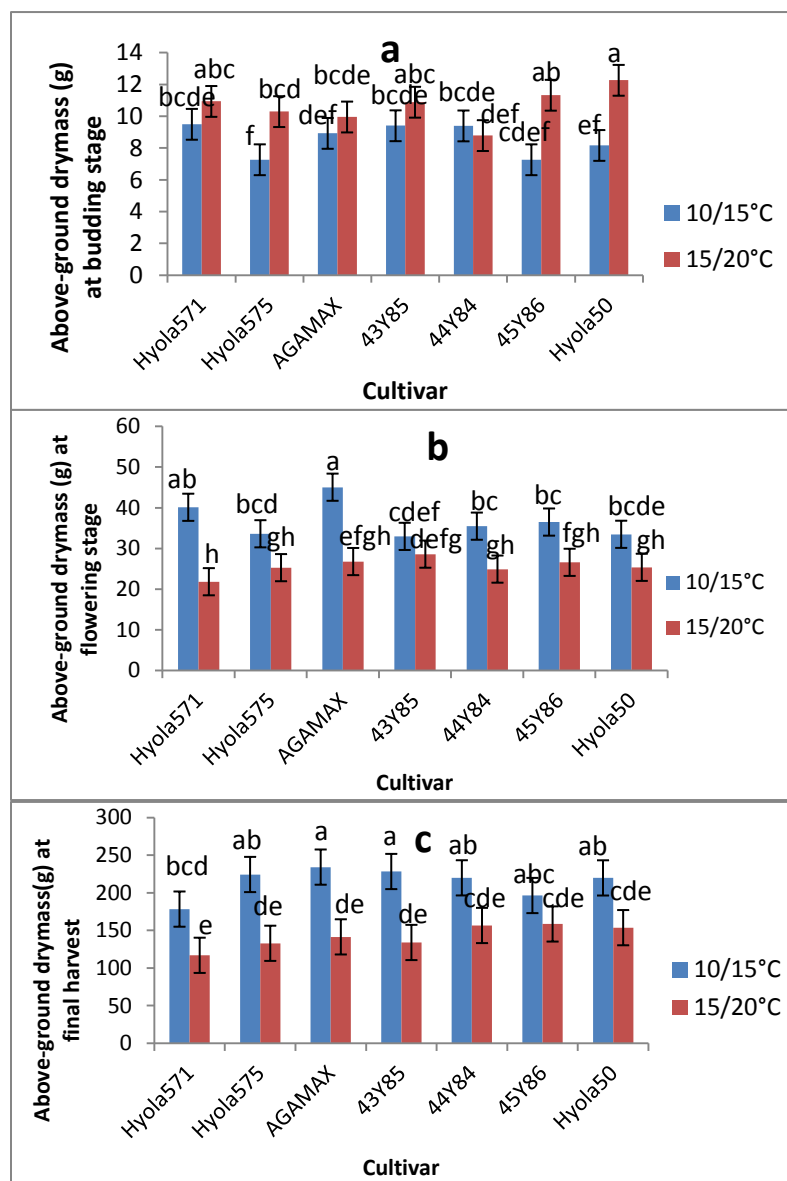
266 At final harvest (FH), no significant interaction between growing temperature regime and cultivar was
267 recorded with dry mass of all genotypes reduced at the higher temperature regime of 15/20°C (Figure
268 4). AGAMAX and 43Y85 recorded significantly higher dry mass than all genotypes in the 15/20°C, but
269 only higher than Hyola 571 in the 10/15°C glasshouse. In general early and mid-early maturing types
270 (Hyola 575, Hyola 571, AGAMAX and 43Y85) showed larger reductions in dry mass of 41.31%, 34.69%,
271 39.65% and 40.65% respectively in the higher temperature glasshouse, while mid and mid to mid-early
272 maturing types, 45Y86, Hyola 50 and 44Y84 showed reductions of 18.81%, 30.40% 28.41% respectively.

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

286 Results from this study are in agreement with earlier studies (Qaderi *et al.* 2006, Gou, *et al.*, 2010, Nordli
287 *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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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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300 *3.4 Number of flower stems*

301 Although all genotypes showed a decrease in the number of flower stems when grown at a lower
302 temperature (10/15°C) instead of 15/20°C, differences were only significant for cultivar 44Y84 (Figure
303 5). With the exception of Hyola 575, cultivar 44Y84 produced significantly more flower stems compared
304 to other genotypes at the lower temperature regime of 10/15°C, but at the higher temperature regime
305 (15/20°C) no significant differences were recorded between genotypes tested, except for Hola575 and
306 Hola 50.

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

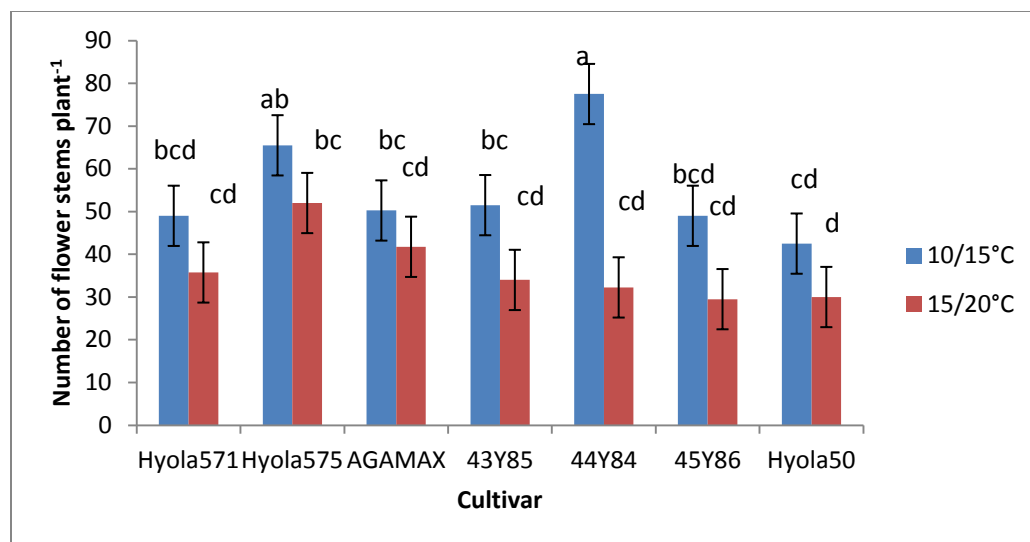
312 Except for the already mentioned difference between 44Y84 and others genotypes at the lower
313 temperature regime, the number of flower stems produced by different genotypes did not show any
314 relationship with their maturity grouping as early and later maturing genotypes produced the same
315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

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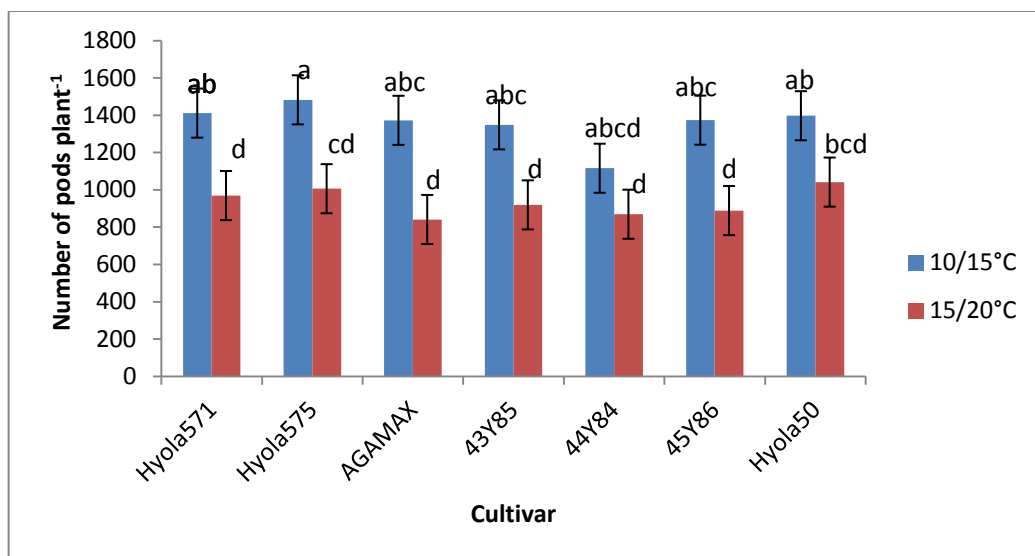


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321 **Figure 5** Flower stems plant⁻¹ of different canola genotypes, measured during the final harvest at growth
 322 stage 5.4 in response to night/ day temperatures of 10/15°C and 15/20°C. Values with the same
 323 alphabetical lettering do not differ 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°C compare to 10/15°C. However, differences between genotypes at both temperature regimes
 329 (10/15°C and 15/20°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.



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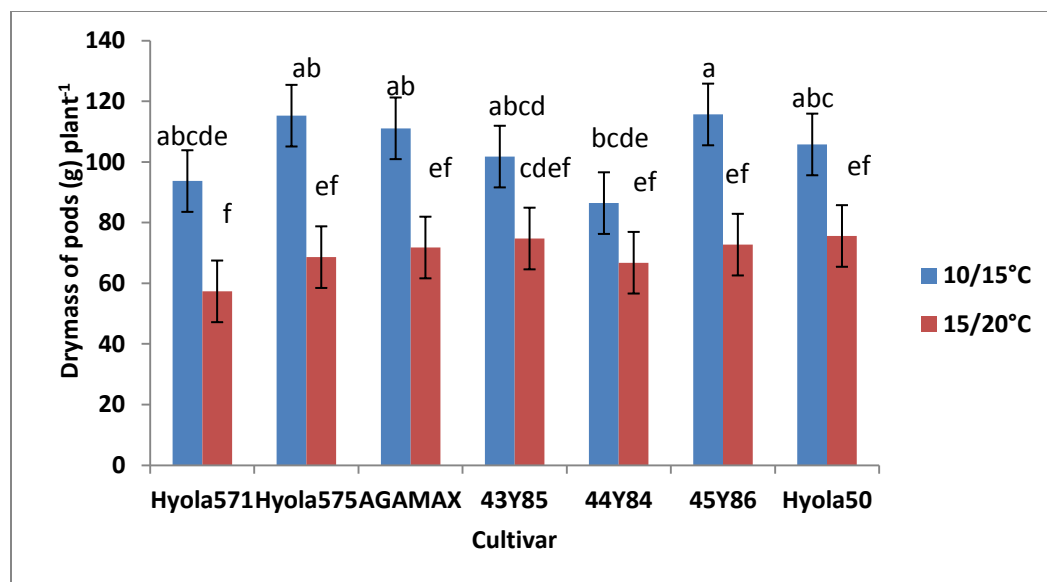
333 **Figure 6** Effect of temperature on number of pods plant⁻¹ of different canola genotypes, measured
 334 during the final harvest at growth stage 5.4 in response to night/ day temperatures of 10/15°C and
 335 15/20°C. Values with the same alphabetical lettering do not differ significantly at P=0.05

336 3.7 Dry mass of pods

337 With exception of 44Y84 and 43Y85, all genotypes showed a significant reduction in dry mass of pods
 338 plant⁻¹ at the 15/20°C temperature regime compared to the 10/15°C temperature regime (Figure 7). Dry
 339 mass of pods varied between about 80 and 116 g plant⁻¹ at the lower day/night temperature of 10/15°C
 340 and differences between genotypes were not significant except for the difference between 45Y86 and
 341 44Y84,. No significant differences between genotypes were recorded at the 15/20°C temperature
 342 regime and the pod dry mass plant⁻¹ varied between about 58 and 72 g. Early maturing Hyola 575 and
 343 Hyola 571 showed higher pods dry mass reductions than mid-maturing Hyola 50 with an increase in
 344 temperature. In contrast to this, early maturing 43Y85 showed less response than mid-maturing 45Y86,
 345 indicating genetic differences between early maturing genotypes.

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

352



353
 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°C and 15/20°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°C temperature regime compared to the
 366 10/15°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°C) temperature regime compared to the
 368 15/20°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°C compared to 0.2075 g plant⁻¹ day⁻¹ for the lower temperature regime
 371 (10/15°C). At the 15/20°C temperature regime, 45Y86 showed highest PGR, while Hyola 571 recorded
 372 the highest PGR at the 10/15°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°C temperature regime compared to 1.2780 g plant⁻¹ day⁻¹ on average at the 15/20°C temperature
375 regime. At the 10/15°C temperature regime, AGAMAX recorded highest PGR, whereas at 15/20°C
376 temperature regime 43Y86 showed the highest PGR. Genotypes also showed a higher PGR at the lower
377 temperature regime of 10/15°C compared to higher temperature regime (15/20°C) from flowering to
378 physiological maturity. At the 10/15°C temperature regime genotypes grew at 2.2008 g plant⁻¹ day⁻¹,
379 while at the 15/20°C temperature genotypes grew at 1.8584 g plant⁻¹ day⁻¹. Cultivar, 43Y85 showed the
380 highest PGR at 10/15°C, whereas at 15/20°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°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°C to 17.5°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°C temperature regime (0.1840 g g⁻¹ day⁻¹) than at the 15/20°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°C temperature regime compare to a PGR of
399 0.0610 g g⁻¹ day⁻¹ at the 10/15°C temperature regime . AGAMAX showed the highest RGR at the 10/15°C
400 temperature regime, whereas at 15/20°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°C temperature, while AGAMAX showed the highest RGR at 15/20°C.

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

416 3.8.3 Net assimilation rate (NAR).

417 A higher NAR of 0.00136 g cm⁻¹ day⁻¹ was recorded by genotypes at both temperature regimes from
418 budding to flowering when compared to the 0.00083 g cm⁻¹ day⁻¹ from flowering to physiological
419 maturity. From budding to flowering genotypes recorded higher NAR of 0.00161 g cm⁻¹ day⁻¹ at 10/15°C
420 temperature regime compared to the 0.00111 g cm⁻¹ day⁻¹ at the 15/20°C temperature regime. From
421 flowering to physiological maturity there was no difference between NAR at different temperature
422 regimes. Genotypes of the same maturity groups did not show similar NAR values at different sampling
423 stage or temperature regimes

424 At the 10/15°C temperature regime Hyola571 recorded the highest NAR from budding to flowering,
425 while 43Y85 showed the highest NAR at 15/20°C. From flowering to physiological maturity there were
426 no difference between temperature regimes but genotypes did differ. At the 10/15°C temperature
427 regime Hyola 575 showed the highest NAR, whereas all genotypes, with the exception of 43Y85, showed
428 NAR values of 0.008-0.009 g cm⁻¹ day⁻¹ at the 15/20°C temperature regime.

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

435

436 **Table 1** Effect of temperature on plant growth rate (PGR) ($\text{g plant}^{-1}\text{day}^{-1}$), relative growth rate of plants
 437 (RGR)($\text{g g}^{-1} \text{day}^{-1}$) and net assimilation rate of plants (NAR) ($\text{g cm}^{-2}\text{day}^{-1}$) 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°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°Cmean		0.2075	1.6124	0.184	0.00161	2.2008	0.061	0.00083
15/20°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°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)

441 4.0 Conclusions

442 The study demonstrated that an increase in night/day temperature from 10/15°C to 15/20°C resulted
443 in an increase in plant height, leaf number at budding stage, leaf area at budding, plant growth rate
444 from planting to budding stage, but reduces plant growth rate from budding to physiological maturity,
445 net assimilation rate from budding to flowering stage, leaf area at flowering and physiological maturity
446 stages, as well as the number of flower stems, number of pods plant⁻¹, above ground I dry mass at
447 flowering and physiological maturity stages and pod dry mass at physiological maturity stage by 22.24%
448 to 40.35%.

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

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