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Optimum time of sowing for rainfed winter chickpea with one-pass mechanised row-sowing: an example for small-holder farms in north-west Bangladesh

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Abstract

The time of sowing chickpea (*Cicer arietinum* L.) in the High Barind Tract of north-west Bangladesh is critical to crop success. To ensure adequate emergence and subsequent crop growth, chickpea relies on residual soil moisture stored in the profile after rice (*Oryza sativa* L.) cultivated in the preceding rainy season. With the development of mechanised, one-pass minimum tillage sowing, the time between rice harvest and chickpea sowing is decreased, and temperature constraints that limit biomass and/or pod formation and filling may be avoided. Minimum tillage may also limit evaporation from the soil surface compared with traditional, full cultivation procedures. The objective of this study was to identify the optimum sowing time to achieve adequate crop establishment and limit exposure of the chickpea crop to terminal drought and heat stress later in the growing season. Over three experimental seasons, chickpea sowing dates were spread from 22 November to 22 December. Soil water content, crop growth and temperature were monitored to determine the optimum sowing time.

Over all seasons and sowing dates, the volumetric soil water content in the seedbed under minimum tillage remained within 17–34%, a range non-limiting for chickpea establishment in glasshouse and field experiments. Late planting (after 10 December) exposed seedlings to low temperatures (<15°C), which limited biomass formation and extended the vegetative growth phase into periods with high maximum temperatures (>35°C), resulting in unfilled pods and depressed grain yield. The preferred sowing time was determined to be 30 November to 10 December to reduce the risk of high temperatures and low soil water content during chickpea reproductive growth causing terminal heat and drought stress, respectively. Mechanised sowing in one operation allows farmers to optimise their time of sowing to match seed requirements for soil water at emergence and may assist farmers to avoid temperature stresses (both low and high) that constrain chickpea vegetative and reproductive growth.

Additional keywords: abiotic stress, chickpea emergence, minimum tillage, rabi season, sowing time.

Introduction

The success of chickpea (*Cicer arietinum* L.) crops grown after rice (*Oryza sativa* L.) in the winter (rabi) season in the High Barind Tract (HBT) of north-west Bangladesh can be constrained by two factors at sowing. First, drying surface soil can limit crop establishment, and second, delayed sowing or emergence may expose the crop to suboptimal conditions during subsequent crop growth stages. The conventional method of broadcast-sowing of rabi season crops followed by seed incorporation either with bullock-drawn country plough or two-wheel tractor (2WT) with rotary cultivator can exacerbate these problems through excessive soil disturbance. This enhances drying of the tilled surface soil and delays sowing, which can lead to sowing of the crop outside of the optimal sowing window.

After the harvest of the rice crop, the surface soil in the HBT can dry quickly because of high temperatures and evaporation rates and become hardsetting (Musa *et al*. 2001). Hence, soil water content in the seedbed is often less than optimal for chickpea establishment by traditional seeding and tillage methods. With rapid germination and emergence, seedling roots are able to penetrate into the subsoil quickly, with a greater likelihood of achieving adequate plant stands and acceptable grain yields (Fyfield and Gregory 1989; Harris *et al*. 1999; Gan *et al*. 2002). Rapid and healthy crop establishment leads to strong root development, which minimises effects of future drought stress. Additional limitations of the broadcast method of sowing are the irregular aggregate size of the seedbed, erratic seed and fertiliser placement in the seedbed, uneven depth of seed placement and soil coverage of seed, and poor seed–soil contact.

The recommended sowing time for chickpea in the HBT, using broadcast seeding and a fully tilled seedbed, is from October to the first week of November (BARI 2010). The actual sowing time depends on when the rice crop is harvested, which may not coincide with when the soil water is optimal for tillage and sowing. However, Johansen *et al*. (2008) recommended that sowing of chickpea occur between late November and early December, largely to limit the prevalence of botrytis grey mould (BGM, caused by *Botrytis cinerea*), which is the major chickpea disease in Bangladesh.

Delayed sowing beyond early December can negatively affect the chickpea crop in relation to crop water requirements and temperatures within the growing season (Kabir *et al*. 2009; Ahmed *et al*. 2011). It can cause the seedlings to emerge under cold temperatures, slowing the rate of early growth (Chaturvedi and Ali 2004; Johansen *et al*. 2008). Specifically, <15°C is the temperature below which vegetative growth, flower production and podset may be limited (Saxena and Johansen 1988; Clarke and Siddique 2004; Kumar *et al*. 2010). In addition, because of very little in-season rainfall, the crop relies on residual soil water in the profile for growth, which can be severely depleted towards crop maturity when ambient temperatures also increase (Rahman *et al*. 2000; Johansen *et al*. 2008). Any delay to crop establishment postpones both flowering and podding and may lead to chickpea podfill and seed development occurring under high temperatures and a drying soil water profile, resulting in terminal drought stress, heat stress and reduced yield (Wang *et al*. 2006; Gaur *et al*. 2008). Studies by Summerfield *et al*. (1984) and Wang *et al*. (2006) showed that prolonged periods at 35°C (day temperature) decreased pod number and seed yields. A recent review by Devasirvatham *et al*. (2012) concluded that temperatures ≥30°C limit flowering and pod development in chickpea.

The development of mechanised row-sowing, independent of the level of soil disturbance (from full tillage through to zero tillage), allows sowing of the chickpea crop in a single pass and expands the area of land that can be planted within the optimum sowing window (Johansen *et al*. 2012). It is hypothesised that mechanised row-sowing will facilitate timely sowing and ensure chickpea establishment within the optimum sowing window while minimising exposure of the chickpea crop to high temperatures and terminal drought later in the growing season.

The optimum sowing time for chickpea in the HBT of Bangladesh needs to be determined for newly available, mechanised row-sowing techniques (Johansen *et al*. 2012). The objective of this study was to identify the window for optimum sowing in the HBT to achieve non-limiting soil physical properties at sowing by mechanised row-sowing and limit exposure of the chickpea crop to terminal drought and heat stress.

Materials and methods

Three field trials were conducted in farmers' fields in the HBT of Bangladesh to determine the optimum range of soil volumetric water content (θ_v) within which chickpea seeds will germinate and emerge in the field environment. The trials were established in three growing seasons (2007–08, 2008–09, 2009–10), with sowing dates spread from 22 November to 22 December. The soils at all locations had a silt loam surface and were classified as Grey terrace soil, Aeric Haplaquept (USDA Soil Taxonomy (Soil Survey Staff 2010)), or Eutric Gleysol (World Reference Base) (Catling 1992; Brammer 1996; IUSS Working Group 2006).

Desi-type chickpea seed, cv. BARI Chola 5, was sown in all trials. Sowing rates of 38-45 kg ha^{-1} were used with the aim of creating a plant stand of ~20 plants m^{-2}. In all trials, seeds were primed with water for 4 h, drained and surface-dried before sowing (Musa *et al*. 2001). In all trials, Roundup® (glyphosate 360 g L^{-1}) was applied across the entire plot before the first sowing date. Table 1 outlines the details of these trials, specifying the differences among them in management. The 2007–08 trial site had been irrigated from runoff from an adjacent irrigated field while the previous rice crop was awaiting harvest, but no details of volume of water applied were recorded.

For all sowing operations, a two-wheel tractor, originally designed for full rotary tillage but modified for strip tillage (ST), was used (Johansen *et al*. 2012). For ST, four rotary cutting blades were arranged in front of each furrow opener, creating an approximately 10-cm-wide strip of disturbed soil in which the seed and fertiliser were placed. The remaining area between the strips was undisturbed. The furrow opener delivers both seed and fertiliser behind the rotary blades and was followed by a pressing roller. The furrow opening to drop seed and fertiliser was made by a narrow leading-edge tine (Haque *et al*. 2004). In each year, the same machinery operator sowed all treatments to minimise any effect of operator technique and experience.

Weather

Daily temperature and rainfall data were collected from the Bangladesh Rice Research Institute at Edulpur Village, Godagari Upazilla, Rajshahi District, ~10 km from the trial sites.

The number of days within the growing season when daily minimum temperatures and maximum temperatures were at limiting levels of ≤15°C and ≥35°C, respectively, were calculated. In addition, 39 years of historical weather data from the Rajshahi District weather station (BARC 2011) were interrogated to determine the probability of temperature conditions found in 2007–08, 2008–09 and 2009–10 occurring in any year.

Soil water content

Soil water content was monitored from before sowing to after emergence of the crop. Volumetric soil water content (θ_v) was measured by frequency domain reflectometry using the MP406 soil water probe (θ_{probe}) (ICT International, Armidale, NSW, Australia) in the soil surface at depths of 0–6 and 6–12 cm. The probe needles were 6 cm long and inserted at 6–12 cm after removing the soil above with an auger. During all experimental seasons, gravimetric soil water contents were also collected and converted to θ_v by means of bulk density (Cresswell and Hamilton 2002). The pairs of data (n = 116) comprising calculated θ_v and volumetric water content from the MP406 (θ_{probe}) were used to construct a calibration curve generic to the HBT soil ($\theta_v = 0.918(\theta_{probe}) - 5.1543$; $r^2 = 0.77$). Across the 3 years, the soil water was measured at one or more of the following periods: (*i*) from the harvest of the rice crop until sowing to monitor the drying down of the surface soil (2007 only), (*ii*) on the day chickpea was sown, and (*iii*) when it was deemed no further emergence would occur.

Plant measurements

In all years, the dates were recorded when 50% of plants in a plot had flowered, when 50% of plants in a plot had formed pods, and at crop physiological maturity. In the 2008–09 trial, physiological maturity was recorded only for the first and last sowing dates. Plant stands after final emergence were counted (2007–08, whole plot; 2008–09, four rows by 1-m lengths in each plot; 2009–10, two quadrats per plot, three rows wide by 1-m length).

Final aboveground biomass and grain yields were measured from the whole plot in 2007–08 and 2008–09, whereas in 2009–10, two quadrats per plot were harvested (three rows by 1-m length). All plant material was air-dried in the sun, and these weights are reported. Additional plant growth parameters recorded in 2009–10 from quadrats were pod weight, pod number and number of filled pods. In addition, in 2007–08, 10 plants were selected per plot and aboveground biomass and grain weights determined. For final harvest, plants were cut at ground level and biomass and grain yield were determined once the plants had air-dried. Seeds were removed from pods by manual threshing of pods that were first sun-dried. In all cases, biomass includes all aboveground plant biomass.

Statistical analyses

Results were analysed using Genstat Release 11.1 (VSN International Ltd, Hemel Hempstead, UK). Analyses of variance (ANOVA) or residual maximum likelihood (REML) (where unequal replication of treatment combinations occurred) were used to examine treatment differences. The means, standard error of the means and the least significant differences (l.s.d.) are reported as necessary. Where REML was used, the estimated means from the model and the average l.s.d. are reported.

The effects of temperature on days from sowing to flowering (vegetative growth stage) and days from podding to physiological maturity (reproductive growth stage) were examined. The temperature parameters of mean minimum temperature (Tmin), mean maximum temperature (Tmax), and the number of days when daily minimum temperatures and maximum temperatures were at limiting levels of ≤15°C (Days ≤15°C) and ≥35°C (Days≥35°C), respectively, were calculated for each growing stage. The data from the three growing seasons were combined (2007–08, 2008–09, 2009–10). For each phenological growth stage, an all-subsets regression using forward selection was carried out. From this it was determined which temperature variables for the growth stage should be included as explanatory variables in a generalised linear model to explain the length of that growth stage.

Results

Weather and crop phenology

The temperature and rainfall data are shown for the 2007–08, 2008–09 and 2009–10 rabi seasons (Fig. 1). In 2007–08 and 2008–09, within-season rainfall was 10.2 and 31.2 mm, respectively; in 2009–10 there was no within-season rainfall. After sowing of the rabi crop in November (all years), temperatures decreased into December and remained low during January. Maximum temperatures during this period are <25°C and minimum temperatures are as low as 10°C. Temperatures began to rise again during February and reached maxima ≥30°C by March. Figure 1 also shows the dates of phenological stages of all trials. Sowing dates in each trial are designated as SD1 to SD8 as appropriate.

The range in sowing days was 13, 14 and 19 days for 2007–08, 2008–09 and 2009–10 trials, respectively. The duration of crop growth decreased with sowing date in all years. In the 2007–08 trial, growth duration decreased from 124 to 117 days, whereas in 2008–09 and 2009–10 trials, growth duration decreased from 119 to 116 days. Chickpea took longer to flower in 2007–08 and 2009–10 trials than in the 2008–09 trial, but had a shortened reproductive growth phase. The number of days from podding to maturity was 43–46 days in the 2007–08 trial, 38–40 days in the 2009–10 trial, and 55–57 days in the 2008–09 trial.

The Tmax and Tmin from sowing to podding in the 2009–10 season (23°C and 12°C) were lower than in the 2008–09 season (25°C and 15°C) (Fig. 1), whereas in 2007–08 the corresponding temperatures for this period were 25°C and 12°C. By contrast, the Tmax and Tmin from podding to maturity were greater in 2009–10 (35°C and 22°C) than in 2007–08 (33°C and 20°C) and 2008–09 (29°C and 17°C). When the sowing date of 6 December was compared across these years, the increase in temperatures was 4°C (Tmax) and 3°C (Tmin) between the 2008–09 and 2009–10 trials.

Both Tmin and Tmax had negative correlations with days from sowing to flowering, whereas Days ≤15°C had a positive correlation (Table 2). An all-subsets regression using the forward selection of temperature parameters was completed with days of vegetative growth stage as the response variable. The Days ≤15°C explained 84% of the variation in the model ($P < 0.001$), with an estimated residual of 3.21 days. Adding Tmin and Tmax for the period explained an additional 3% of the variation.

There was a negative correlation between the number of days from podding to maturity and the temperature parameters of Tmin, Tmax and Days ≥35°C. Again, Days ≤15°C during the period had a positive correlation (Table 3). A second all-subsets regression using the forward selection of temperature parameters was completed with days from podding to physiological maturity—the reproductive growth stage—as the response variable. For this analysis, the Tmin and Tmax during the period were significant ($P \leq 0.001$) and were included in the model. Days ≤15°C and Days ≥35°C were not included ($P > 0.232$). When the two variables (Tmin and Tmax) were included in the model, 95% of variance was explained ($P < 0.001$), with an estimated residual error of 1.47°C. The regression coefficients for the variables were 8.75 (±1.6) for Tmin and –9.83 (±1.35) for Tmax.

Soil water content

The date of harvest of the previous rice crop and antecedent rainfall and temperature determined the initial surface (0–6 cm) θ_v, which before the first sowing event was 27–34% (all years) (Fig. 2). Surface θ_v decreased over successive sowing dates but sowing occurred within the water content range of 21.9–33.5%.

The wettest range of θ_v at crop establishment was in the 2007–08 trial (Fig. 2), in which the site had been irrigated when the previous rice crop was awaiting harvest. Therefore, soil water content at sowing was higher than usual for most fields at this time of year. The θ_v at 0–6 cm was 33.5% during the first sowing and dried to 27.8% in the last sowing. In the 2007–08 trial, the θ_v at 19 days after the last sowing in the 0–6 cm layer within the seed-row was not different from that between rows, and at 29.6% was only 2.9% less than the θ_v at sowing. The θ_v between rows did not differ with sowing date treatment (26.6%). This represents a loss of 1.2–4.6% from the original θ_v at sowing.

In the 2008–09 trial at crop establishment, the θ_v in the 0–6 cm layer ranged from 21.3 to 28.3% ($P < 0.01$; l.s.d. ($P = 0.05$) 3.57) (Fig. 2). Soil water decreased over the sowing period, and generally the earlier sowings (22 November–28 November) were into significantly wetter soil than the later sowings (30 November–6 December). The θ_v in the 6–12 cm layer of soil followed the same drying trend as the surface, for the most part. The θ_v in the 0–6 cm layer in the seed-row measured 10 days after the last sowing was 21.8–24.7% and did not differ among sowing date treatments. Soil water had declined by 4% from the first sowing date (22 November) to 16 December when chickpea plant emergence was counted. In the 2009–10 trial, the soil water at 0–6 cm ranged from 16.9 to 27.4% ($P < 0.001$, l.s.d. 2.87) and each later sowing date was significantly dryer than the previous one. The θ_v in the 6–12 cm layer ranged from 26.6 to 28.3% and was higher than in the 0–6 cm layer at the last two sowing dates. In the 2009–10 trial, when the θ_v was determined 10 days after the last sowing date, the θ_v in the seed-row was 13.1%, with no significant difference across sowing dates. The θ_v was higher between the rows than within the rows, being 17.2% at 0–6 cm depth and 23% at 6–12 cm depth.

Plant number at emergence

In all years the emergence of chickpeas across the sowing dates showed no trend with sowing date (Fig. 3) nor, therefore, with changes in θ_v. In the 2007–08 trial, the number of emerged plants was 12–19 plants m^{-2}. For all sowing dates in the 2008–09 and 2009–10 trials, the mean number of plants emerged was above the target of 20 plants m^{-2}. The final number of plants emerged in the 2007–08 trial, 17 ± 1.08 plants m^{-2}, was less than the mean number of plants in 2008–09 and 2009–10 trials (35 and 28 plants m^{-2}, respectively).

Chickpea growth and yield

There were no apparent constraints due to disease (BGM, collar rot, wilt), insect (pod-borer) or weeds in these trials, because effective control measures were applied (Table 1). Thus in the present study, sowing date effects can be uniquely attributed to soil and weather conditions.

At flowering in the 2007–08 trial, the chickpea biomass per plant was 2.4–3.8 g $plant^{-1}$, whereas at harvest it was 5.9–8.8 g $plant^{-1}$ (Fig. 4). There was no effect of sowing date on plant biomass at either time. At harvest, there were 35–55 pods $plant^{-1}$ with a mean of 43 pods $plant^{-1}$ across all sowing dates. The grain yield (P = 0.076, l.s.d. 248) and biomass (P = 0.034, l.s.d. 459) suggest that the 7 December sowing had lower yield than 11 December sowings (Fig. 5).

In the 2008–09 trial, there was an increase in grain yield (Fig. 5) and biomass (Table 4) from the first sowing date (22 November) to 30 November, and generally, the yield and biomass of the 2 December sowing date were significantly higher than the three earliest and two latest sowing dates. Pod weight at 50% podding was also lower in the later sown treatments (Table 4), whereas aboveground biomass at 50% podding showed a similar trend but values were not significantly different.

At final harvest in the 2009–10 trial, the aboveground biomass and pod weight measured in quadrats were greater in the treatments sown on 3 and 6 December than in those sown on 14 and 22 December ($P < 0.01$ and $P < 0.001$, respectively) (Fig. 6). The highest grain yield, at 775 kg ha^{-1}, was from the chickpea sown on 6 December (Fig. 5), but crops sown on 3 and 6 December were not different in grain yield ($P = 0.017$). Of the later sowing dates, chickpea sown on 14 December had significantly lower grain yield than that sown on 6 December, and chickpea sown on 22 December had significantly lower grain yield than crops sown on 3 and 6 December. Pod numbers were less for sowing dates 14 and 22 December than for the previous two dates ($P < 0.001$), and the percentage of unfilled pods increased from 10 to 28% with the later sowing date.

Discussion

Drying pattern of surface soil

During the sowing period of all three consecutive years, surface θ_v was 17–33% and chickpea emergence was successful. In glasshouse studies, optimum θ_v for emergence was 24–25%, and outside the optimum range of θ_v to 16–33% emergence was delayed but successful (Vance *et al*. 2010). Across the 3 years of the study, there was no correlation between soil water content and plant population at emergence. Given that the soil water contents were not at limiting levels and the seed was primed, this was not surprising. The measurements of θ_v during sowing in all seasons showed a loss of 7–10% from first to final sowing. When this drying period is extended to include final emergence of the chickpea (which may be 1 month after the rice harvest), only the 2009–10 trial showed values of θ_v in the surface soil that were limiting to chickpea establishment in this soil type, as shown in the glasshouse studies (Vance *et al*. 2010). Surface soil water contents as low as this would be an impediment to chickpea crop establishment. However, such late sowing of chickpea is not recommended, because the agronomic growth requirements of the chickpea at flowering and pod-filling stages would not be met (Saxena 1987; Chaturvedi and Ali 2004; Canci and Toker 2009).

Effect of weather parameters on crop growth

Daylengths begin to increase on 21 December, so the majority of chickpea growth is under increasing daylengths. The range in sowing dates means that later sown chickpea crops were under longer daylengths for more of their growth than earlier sown crops; this corresponded to decreased durations of vegetative and total growth with later sowing. Increased daylength can enhance flowering and reduce vegetative growth (Roberts *et al*. 1980; Ahmed *et al*. 2011). The combination of increased daylength and high temperatures induces earlier maturity and decreases grain yields (Ahmed *et al*. 2011). Ahmed *et al*. (2011) reported a decrease of 7–8 days for reproductive growth when sowing date was delayed from 10 November to 30 November, similar to our decrease in duration of growth.

When the conditions at sowing are not limiting to chickpea establishment, grain yields are determined by vegetative and reproductive growth within the season. Across the optimum sowing window of 30 November to 10 December, when grain yields (Fig. 5) and soil water content at sowing are considered, the small differences in daylength will have little effect on crop phenology. However, minimum and maximum temperatures will vary from year to year during the sowing window, and in the present study, the timing and duration of lower temperatures early in the growing season and hotter temperatures later in the growing season provide some indication of why the duration of vegetative and reproductive growth and crop yields differed with sowing date and between seasons.

During vegetative growth in the 2009–10 trial, 58–72 days had minimum temperatures ≤15°C, whereas in the 2008–09 trial, this was 33–42 days. Analysis of historical weather data for this period indicates a 98% chance of >48 days with minimum temperatures ≤15°C. This indicates a high likelihood of periods of low temperature during the vegetative growth stage. For all sowing dates of the 2009–10 trial and the last two sowing dates of the 2008–09 trial, plants had reduced early growth and vigour, symptoms commonly reported in the region at low temperatures (Johansen *et al*. 2008). The significant drop in yields for the final two sowing dates in the 2008–09 trial was evident in the pod weight at 50% podding and grain yield, both of which were less than for the previous sowing dates. Emergence for these two latest sowing dates in the 2008–09 trial occurred when maximum temperatures dropped over a period of 10 days from 30°C to 17°C, before stabilising again at 25°C (Fig. 1).

Another instance of low temperatures during the growing season affecting crop growth was during reproductive growth in the 2008–09 trial. The 2008–09 trial data show a relationship between grain yield and sowing date, with grain yield increasing with each successive sowing date until the last two sowings, when grain yield fell by 252–392 kg ha^{-1}. In contrast to late-sown crops that encounter low temperatures at emergence, the lower yields of the early-sown crops may be associated with the number of days when the minimum temperature was <15°C during the reproductive phase of chickpea growth. Chickpea will continue to cycle through flowering and flower abortion when temperatures remain <14-16°C, whereas pod formation is delayed at 16°C and prevented at 10-12°C (Croser *et al*. 2003; Berger *et al*. 2004). In India, it has been reported that poor podset can occur when day temperatures are <20°C and night temperatures <10°C (Saxena 1980; Saxena and Johansen 1988; Saxena *et al*. 1988; Kumar *et al*. 2010). Minimum temperatures can be a factor in preventing podset from flowers (Saxena 1980). For the 2008–09 trial, from 15 January to 20 February, the minimum temperature was 13-15°C. This is not an uncommon occurrence in the region; analysis of the 39 years of historical weather data showed that 24–37 days during this period had minimum temperatures ≤15°C. For the first sowing date in the 2008–09 trial, this corresponded to 34 days in the period after 50% flowering during which the crop experienced minimum temperatures of 13-15°C, whereas for the sixth sowing date, only 27 days of this growth phase were at such low temperatures. Although the minimum temperatures did not reach the threshold proposed to limit reproductive growth, the increased numbers of days with minimum temperatures <15°C may have increased loss of flowers and limited pod production (Rahman *et al*. 2000; Clarke and Siddique 2004; Toker *et al*. 2007). With delayed sowing from 22 November to 2 December, grain yields increased incrementally. This may be because the later sown crops experienced fewer days than the early-sown crops at minimum temperatures that delay flowering and pod formation.

High temperatures during reproductive growth of late-sown crops decreased grain yields in the 2009–10 trial. The grain yields for the first two sowing dates were high, whereas the last two sowing dates, which were sown after the recommended last sowing date of early December (Johansen *et al*. 2008), showed greatly reduced grain yields. The crops from the last two sowing dates of the 2009–10 trial were exposed to high temperatures (maximum temperature ≥35°C) for a longer period of their reproductive growth (18–23 days) phase than crops from the early sowing dates of the same year (10–21 days). From analysis of historical weather data, there is a 40% chance of having ≥23 days with a maximum temperatures ≥35°C during this period. High temperatures (35°C) at flowering affect pod formation, whereas high temperatures during pod development affect the number and weight of seeds (Wang *et al*. 2006). Evidence that these weather characteristics affected the growth of chickpea in the 2009–10 trial comes from the percentage of unfilled pods, which increased with later sowing dates from 10% for the sowing on 3 December to 28% for the sowing on 22 December.

Mean maximum and minimum temperatures from sowing to podding were lower in the 2009–10 trial (23°C and 12°C) than in the 2008–09 trial (25°C and 15°C). These lower mean temperatures in the 2009–10 trial increased the time to flowering and to podding from 55 and 61 days, respectively, in 2008–09 to 74 and 79 days respectively in 2009–10, for the sowing dates of 6 December in each year. By contrast, the Tmax and Tmin in the 2009–10 trial from podding to maturity were greater by 3°C and 2°C, respectively, which decreased the duration of reproductive growth by 15–19 days. During the reproductive growth stage from the beginning of March to maturity, there was an increase in Tmax from 30°C in the 2008–09 trial to 33°C in the 2009–10 trial. Day and night temperatures of 35°C and 18°C, respectively, have been found to decrease chickpea yields compared with 30°C day and 10°C night temperatures (Summerfield *et al*. 1981; Kumar and Abbo 2001). In the present study, there was no relationship between temperature and yield; however, there was a relationship between temperature and duration of growth stages. When Tmin and Tmax increased, both vegetative and reproductive growth stages decreased in duration. The vegetative growth stage increased in duration when there were more days with minimum temperatures ≤15°C during the period. The duration of reproductive growth has been found to decrease with temperature increases, both the minimum and maximum, in controlled environment experiments, but the additional days of growth in the reproductive phase under the lower temperature do not always translate into higher yields (Roberts *et al*. 1980). In the present study, the two early sowing dates in the 2009–10 trial had yields similar to those in 2008–09 trial, even though there were 15 extra days of reproductive growth in the 2008–09 trial.

The 3 years of the study had comparatively low rainfall for the chickpea growing season compared with the 39 years of historical weather data for the region. The probability of achieving up to 37 mm rainfall for the period, comparable to the 2008 season, was 16%, whereas the likelihood of achieving no rainfall, as happened in 2009, was <1%. The mean total rainfall for the region during this growing season was 62 mm. The likelihood of occurrence of periods in the chickpea growing season where minimum and maximum temperatures, respectively, limit plant growth is 98% and 40%. Although the low rainfall of the three seasons is not representative of historical data, the analyses of temperature constraints during chickpea growth is pertinent to the temperature profiles of historical weather data in the region.

Effect of time of sowing on grain yield

In the present trials, the grain yields tended to increase with a delay in sowing from November to early December, but there was also variability in grain yields among the years and sowing dates (Fig. 5). Whereas highest yields were found in later sown crops for the 2007–08 trial, in the 2008–09 and 2009–10 trials, the later sown crops had the lowest yields of all the crops sown across the years. Crop establishment did vary among sowing times; however, soil water contents at sowing were not limiting to chickpea crop establishment and there was no correlation between yield and plant number.

Other research in Gazipur District (central Bangladesh) found that although chickpea yields peak with sowing in late November, delayed sowing up to early December will still give satisfactory yields, but thereafter yield penalties of 9–38% arise from sowing delayed to 30 December (Kabir *et al*. 2009; Ahmed *et al*. 2011). A series of on-farm field trials run from 1999 to 2002 examined the effect of seed priming on chickpea crops in the HBT (Musa *et al*. 2001). Johansen *et al*. (2008) compiled these data to investigate the effect of sowing date on chickpea yields in the HBT. As sowing dates changed from early November to late December, there was a declining trend in chickpea yield. However, as with the results of the present study, the data also showed that the yields were variable across sowing dates and seasons, with some low yields in early-sown crops and some high yields in later sown crops. Johansen *et al*. (2008) concluded that the combination of good agronomic management and adequate soil moisture will allow adequate yields within a quite wide sowing window. In the present system of mechanised row-sowing, the early-sown crops in the 2008–09 trial did show a lower yield than the later sown crops, and this trend is opposite to the relationship of the data analysed by Johansen *et al*. (2008), in which the highest yields were obtained from the earlier sowing dates.

A difference between the present trials and the on-farm data collected by Musa *et al*. (2001) is that the latter trials were sown with broadcasting of the seed and fertiliser and full tillage with laddering (soil levelling). This method results in rapid drying of the surface soils and uneven establishment (Johansen *et al*. 2008). Our time-of-sowing trials were all sown by 2WT-mounted planters, which allow the seed and fertiliser to be placed together in a furrow and can provide a more even soil coverage of the sown seed. These conditions were apparently not limiting to chickpea establishment, and the crops sown earlier avoided low temperatures during early seedling growth. However, sowing date, soil water content at sowing and the vigour of the emerged plants are not the only indicators of potential yield. The differences in final yield of chickpea crops may also be attributed to conditions faced later in the season, such as the rate of plant water use, in-season rainfall and temperatures, biotic stresses (BGM, pod-borer, collar rot), nutrient deficiencies, and effectiveness of nodulation.

Conclusion

Under mechanised row-sowing over three planting seasons, soil water content did not limit chickpea establishment from early November to late December in the HBT of Bangladesh. Soil water contents in the surface remained at 17–33%, values that would not limit chickpea crop establishment. From the present field results, it was inferred that periods of high or low temperature limited chickpea growth in the HBT. The apparent roles of daily temperatures in chickpea growth were as follows:

1. Vegetative growth stage was lengthened where the chickpea crops were at minimum temperatures <15°C for prolonged periods during vegetative growth.

2. Grain yield was depressed because of more unfilled pods and the duration of reproductive growth stage was decreased where maximum temperatures were >35°C for a significant period.

3. Lower grain yields occurred, possibly from loss of flowers and limited pod production, if the chickpea plants encountered lower minimum temperatures (13-15°C) during reproductive growth from flowering and during early podding.

4. Days to reach 50% flowering and 50% podding were increased if the chickpea crops were sown very late, because of lower mean temperatures (both maximum and minimum) from sowing to podding. The later sown crops additionally experienced higher mean temperatures subsequently, during reproductive growth, which decreased the duration of the growth stage and led to more unfilled pods and lower grain yields.

Considering the grain yields for 2007–08, 2008–09 and 2009–10 trials, the optimum sowing time by 2WT-mounted planter was 30 November to 10 December. The recommended cutoff time for sowing of chickpea crops in the HBT, based on previous studies with conventional broadcast seeding and full tillage, remains valid for mechanised row-sowing. Selection of the preferred time of sowing is more feasible with mechanised, one-pass row-sowing than with conventional sowing. This would allow farmers to avoid periods of low temperature, which decrease vigour during early seedling growth and increase the duration of the vegetative growth phase, and to avoid the onset and duration of high temperatures later in the season.

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References

Ahmed F, Islam MN, Janan MA, Rahman MT, Ali MZ (2011) Phenology, growth and yield of chickpea as influenced by weather variables under different sowing dates. *Journal of Experimental Bioscience* **2**, 83–88.

BARC (2011) Databases & statistics. Climatic and hydrological information. Bangladesh Agricultural Research Council. Available at: www.barc.gov.bd/data_stat.php (accessed 18 October 2011).

BARI (2010) BARI Technology Search (Commodity). Bangladesh Agricultural Research Institute, Bangladesh. Available at: www.bari.gov.bd/index.php?option=com_advancedsearch&view=advancedsearch&id=913&page_no=0 (accessed 31 December 2010).

Berger JD, Turner NC, Siddique KHM, Knights EJ, Brinsmead RB, Mock I, Edmondson C, Khan TN (2004) Genotype by environment studies across Australia reveal the importance of phenology for chickpea (*Cicer arietinum* L.) improvement. *Australian Journal of Agricultural Research* **55**, 1071–1084.

Brammer H (1996) 'The geography of the soils of Bangladesh.' (The University Press Limited: Dhaka, Bangladesh)

Canci H, Toker C (2009) Evaluation of yield criteria for drought and heat resistance in chickpea (*Cicer arietinum* L.). *Journal of Agronomy & Crop Science* **195**, 47–54.

Catling D (1992) 'Rice in deep water.' (The MacMillan Press Limited: London)

Chaturvedi SK, Ali M (2004) Development of early maturing chickpea varieties for diversification of rice-wheat cropping system. In 'New directions for a diverse planet. Proceedings 4th International Crop Science Congress'. 26 Sept.–1 Oct. 2004, Brisbane, Qld. (Eds T Fischer, N Turner, J Angus, L McIntyre, M Robertson, A Borrell, D Lloyd) (The Regional Institute Ltd: Gosford, NSW) Available at: www.cropscience.org.au/icsc2004/poster/3/4/7/411_chaturvedisk.htm

Clarke HJ, Siddique KHM (2004) Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research* **90**, 323–334.

Cresswell HP, Hamilton GJ (2002) Bulk density and pore space relations. In 'Soil physical measurement and interpretation for land evaluation.' (Eds N McKenzie, K Coughlan, H Cresswell) pp. 35–58. (CSIRO Publishing: Melbourne)

Croser JS, Clarke HJ, Siddique KHM, Khan TN (2003) Low-temperature stress: Implications for chickpea (*Cicer arietinum* L.) improvement. *Critical Reviews in Plant Sciences* **22**, 185–219.

Devasirvatham V, Tan DKY, Gaur PM, Raju TN, Trethowan RM (2012) High temperature tolerance in chickpea and its implications for plant improvement. *Crop & Pasture Science* **63**, 419–428.

Fyfield TP, Gregory PJ (1989) Effects of temperature and water potential on germination, radicle elongation and emergence of mungbean. *Journal of Experimental Botany* **40**, 667–674.

Gan YT, Miller PR, Liu PH, Stevenson FC, McDonald CL (2002) Seedling emergence, pod development, and seed yields of chickpea and dry pea in a semiarid environment. *Canadian Journal of Plant Science* **82**, 531–537.

Gaur PM, Krishnamurthy L, Kashiwagi J (2008) Improving drought-avoidance root traits in chickpea (*Cicer arietinum* L.) – Current status of research at ICRISAT. *Plant Production Science* **11**, 3–11.

Haque ME, Meisner CA, Hossain I, Justice S, Rashid MH, Sayre K (2004) Two-wheeled tractor operated zero till seed drill: a viable crop establishment and resource conservation option. In 'Proceedings of the International Conference. 2004 CIGR International Conference'. 11–14 October 2004, Beijing, China. pp. 203–209. (China Agricultural Science and Technology Press: Beijing)

Harris D, Joshi A, Khan PA, Gothkar P, Sodhi PS (1999) On-farm seed priming in semi-arid agriculture: Development and evaluation in maize, rice and chickpea in India using participatory methods. *Experimental Agriculture* **35**, 15–29.

IUSS Working Group (2006) 'World reference base for soil resources 2006.' 2nd edn. World Soil Resources Reports No. 103. (FAO: Rome)

Johansen C, Musa AM, Harris D, Islam MS, Ali MO (2008) Integration of chickpea and other rabi crops into rainfed rice-based sytems of the High Barind Tract. In 'Improving agricultural productivity in rice-based systems of the High Barind Tract of Bangladesh'. (Eds CR Riches, D Harris, DE Johnson, B Hardy) pp. 135–146. (International Rice Research Institute: Los Baños, Philippines)

Johansen C, Haque ME, Bell RW, Thierfelder C, Esdaile RJ (2012) Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. *Field Crops Research* **132**, 18–32.

Kabir AHMF, Bari MN, Karim MA, Khaliq QA, Ahmed JA (2009) Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed conditions. *Bangladesh Journal of Agricultural Research* **34**, 335–342.

Kumar J, Abbo S (2001) Genetics of flowering time in chickpea and its bearing on productivity in semiarid environments. *Advances in Agronomy* **72**, 107–138.

Kumar S, Nayyar H, Bhanwara RK, Upadhyaya HD (2010) Chilling stress effects on reproductive biology of chickpea. *Journal of SAT Agricultural Research* **8**, 1–14.

Musa AM, Harris D, Johansen C, Kumar J (2001) Short duration chickpea to replace fallow after aman rice: The role of on-farm seed priming in the High Barind Tract of Bangladesh. *Experimental Agriculture* **37**, 509–521.

Rahman MM, Bakr MA, Mia MF, Idris KM, Gowda CLL, Kumar J, Deb UK, Malek MA, Sobhan A (2000) Legumes in Bangladesh. In 'Legumes in rice and wheat cropping systems of the Indo-Gangetic plain-Constraints and opportunities'. (Eds C Johansen, JM Duxbury, SM Virmani, CLL Gowda, S Pande, PK Joshi) pp. 5–34. (International Crops Research Institute for the Semi-Arid Tropics/Cornell University: Hyderabad, AP, India)

Roberts EH, Summerfield RJ, Minchin FR, Hadley P (1980) Phenology of chickpeas (*Cicer arietinum*) in contrasting aerial environments. *Experimental Agriculture* **16**, 343–360.

Saxena NP (1980) Pod setting in relation to temperature at Hissar. *International Chickpea Newsletter* **2**, 11–12.

Saxena MC (1987) Agronomy of chickpea. In 'The chickpea'. (Eds MC Saxena, KB Singh) pp. 207–231. (CAB International: Wallingford, UK)

Saxena NP, Johansen C (1988) Realized yield potential in chickpea and physiological considerations for further genetic improvement. In ‘Proceedings International Congress of Plant Physiology’. 15–20 February 1988, New Delhi, India. (Eds SK Singa, PV Sane, SC Bhargava, PK Agrawal) pp. 279–288. (Society for Plant Physiology and Biochemistry: New Delhi) Available at: http://oar.icrisat.org/4479/

Saxena NP, Johansen C, Sethi SC, Talwar HS, Krishnamurthy L (1988) Improving harvest index in chickpea through incorporation of cold tolerance. *International Chickpea Newsletter* **19**, 17–19.

Soil Survey Staff (2010) ‘Keys to Soil Taxonomy.’ 11th edn (USDA-Natural Resources Conservation Service: Washington, DC)

Summerfield RJ, Minchin FR, Roberts EH, Hadley P (1981) Adaption to contrasting aerial environments in chickpea (*Cicer arietinum* L.). *Tropical Agriculture (Trinidad)* **58**, 97–113.

Summerfield RJ, Hadley P, Roberts EH, Minchin FR, Rawsthorne S (1984) Sensitivity of chickpea (*Cicer arietinum*) to hot temperatures during the reproductive period. *Experimental Agriculture* **20**, 77–93.

Toker C, Lluch C, Tejera NA, Serraj R, Siddique KHM (2007) Abiotic stresses. In ‘Chickpea breeding and management’. (Eds SS Yadav, RJ Redden, W Chen, B Sharma) pp. 474–496. (CABI: Wallingford, UK)

Vance W, Bell RW, Johansen C (2010) Soil physical conditions that limit chickpea emergence with particular reference to the High Barind Tract of Bangladesh. In ‘Soil solutions for a changing world. Proceedings 19th World Congress of Soil Science,’. 1–6 August 2010, Brisbane. (Eds RJ Gilkes, N Prakongkep) pp. 236–239. (IUSS: Australia) Available at: www.iuss.org/19th%20WCSS/Symposium/pdf/0596.pdf

Wang J, Gan YT, Clarke F, McDonald CL (2006) Response of chickpea yield to high temperature stress during reproductive development. *Crop Science* **46**, 2171–2178.

Table 1. Details of location, soil type, experimental treatments, plot design and seed and fertiliser rates for sowing date trials in 2007-08, 2008-09 and 2009-10 in the High Barind Tract , Godagari Upazilla, Rajshahi District, Bangladesh.

	Growing season		
	2007-08	2008-09	2009-10
Location	Choyghati Village	Nagirpur Village	Choyghati Village
Sowing dates	4 sowing dates: 1, 4, 11, 14 December	8 sowing dates: 22, 24, 26, 28, 30 November and 2, 4, 6 December	4 sowing dates: 3, 6, 14, 22 December
Tillage types	Strip (ST)	ST	ST
Design	Split plot Main plot – sowing date Sub plot – tillage type	Complete randomized block	Complete randomized block
Replication	4	4, except 6 December which had 12 reps	4
Row spacing	50 cm	40 cm	30 cm
Plot dimensions	6 rows 10 m long	8 rows 10 m long	12 rows 12.8 m long
Seed rate	38 kg ha^{-1}	40 to 45 kg ha^{-1}	45 kg ha^{-1}
Fertiliser rate	Triple superphosphate (TSP) 50 kg ha^{-1}	TSP 100 kg ha^{-1}	TSP 100 kg ha^{-1}

Hand weeding	None	12 to 15 January 2009 10 to 13 February 2009	None
Insecticide against pod borer (*Helicoverpa armigera*)	Ripcord®[1] 562 ml ha^{-1} at podding stage	Ripcord® 562 ml ha^{-1} 12, 23 February and 2 March 2009	Ripcord® 562 ml ha^{-1} at podding stage

[1]Ripcord® active ingredient (21.1% Cypermethrin, 70.5% Xylene)

Table 2. The linear regression for the relationship between days from sowing to flowering and the independent variables: days with minimum temperature ≤15°C (Days ≤15); mean minimum temperature for period (Tmin) and; mean maximum temperature for period (Tmax). The data from the three growing seasons (2007-08, 2008-09, 2009-10) was combined. The coefficients with standard errors, significance and correlation coefficient (r) are shown for each variable.

Independent variable	Coefficient	Significance	r
Days with minimum temperature ≤15°C	0.49 (±0.042)	*P* <0.001	0.92
Mean minimum temperature for period	-3.85 (±0.669)	*P* <0.001	0.84
Mean maximum temperature for period	-5.27 (±3.26)		0.40

Table 3. The linear regression for the relationship between days from podding to maturity and the independent variables: days with minimum temperature ≤15°C; mean minimum temperature for period; mean maximum temperature for period and; days with maximum temperature ≥35°C. The data from the three growing seasons (2007-08, 2008-09, 2009-10) was combined. The coefficients with standard errors, significance and correlation coefficient (r) are shown for each variable.

Independent variable	Coefficient	Significance	r
Mean maximum temperature for period	-2.51 (±0.448)	*P* <0.001	0.89
Days with minimum temperature ≤15 °C	0.51 (±0.108)	*P* =0.002	0.85
Mean minimum temperature for period	-2.7 (±0.673)	*P* =0.004	0.82
Days with maximum temperature ≥35 °C	-0.71 (±0.227)	*P* =0.011	0.76

Table 4. Above-ground biomass at 50% podding (g m^{-2}) and harvest (kg ha^{-1}) and pod weight at 50% podding (g m^{-2}) of the chickpea in the 2008-09 time of sowing trial in Rajshahi, Bangladesh. All weights reported are air-dry plant material.

Sowing date	Above-ground biomass at 50% podding (g m^{-2})	Pod weight at 50% podding[3] (g m^{-2})	Above-ground biomass at harvest[3] (kg ha^{-1})
22 Nov	122.3	89.3[db]	761[ab]
24 Nov	137.1	101.2[d]	872[ab]
26 Nov	133.8	99.3[d]	833[ab]
28 Nov	122.5	77.5[bcd]	972[abc]
30 Nov	156.7	77.7[bcd]	1066[bc]
2 Dec	136.3	59.5[ab]	1362[c]
4 Dec	116.3	48.8[ac]	613[a]
6 Dec	119.5	37.1[a]	915[ab]
Mean l.s.d[1].	n.s.[2]	35.8	392
Linear mixed model (REML) *P*-value		0.007	0.039

[1]l.s.d. indicates the least significant difference at $P < 0.05$

[2]n.s. indicates no significant difference

[3]Means in a column with the same superscripts are not significantly different at $P < 0.05$

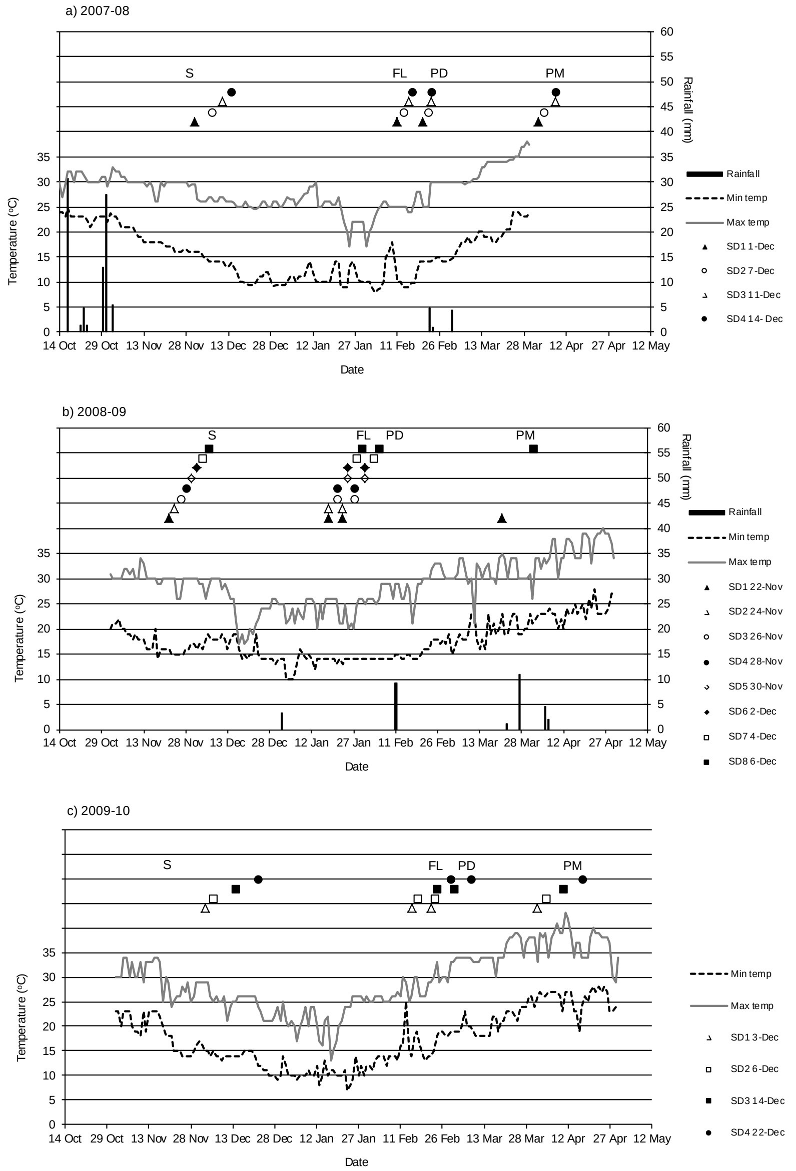

Fig. 1. Weather parameters for the 2007-08, 2008-09 to 2009-10 chickpea growing seasons. Daily minimum and maximum temperature (ºC) are shown with rainfall (mm). No rainfall occurred during the 2009-10 season. For each trial, the dates of phenological development for each sowing date (SD) are shown as symbols on the graph in association with the weather data. Letters on the top of each graph represent the stages of chickpea phenology: S, sowing; FL, flowering; PD, podding; and PM, physiological maturity.

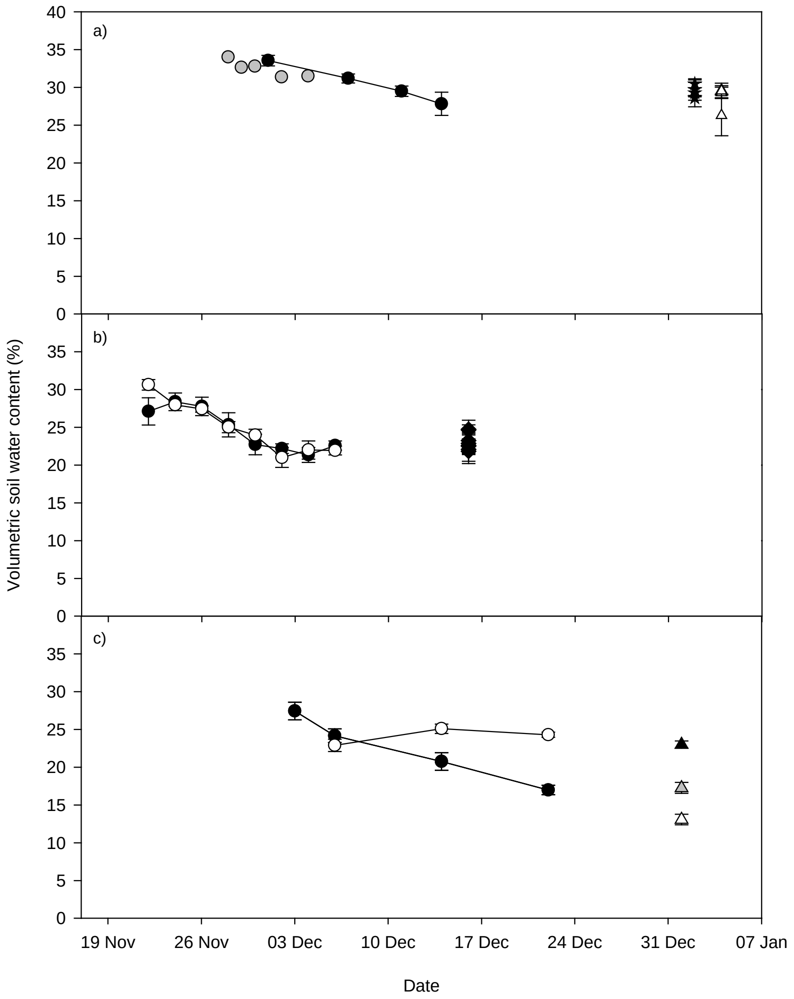

Fig. 2. The volumetric soil water content (θ_v) (%) of the surface soil at sowing in: a) 2007-08, b) 2008-09 and c) 2009-10 trials. In 2007-08, θ_v was measured at 0-6 cm depth on each sowing date (●) (n =20 to 24) and pre-sowing (●) (n =24 to 28). In 2008-09 and 2009-10 trials, θ_v was measured at 0-6 cm (●) and 6-12 cm (○) depth on each sowing date (n=8 to 24). In 2007-08, θ_v was also measured 19 days after the last sowing date within the seed row at 0-6 cm depth (Δ) and between the seed rows at 0-6 cm depth (★) (n =4). In 2008-09, θ_v was also measured ten days after the last sowing date within the seed row at 0-6 cm (♦) depth (n =4 to 12). In 2009-10, θ_v was also measured ten days after the last sowing date within the seed row at 0-6 cm (Δ) depth and between the seed rows at 0-6 cm (▲) and 6-12 cm (▲) depth (n =32). Error bars indicate ± 1 standard error.

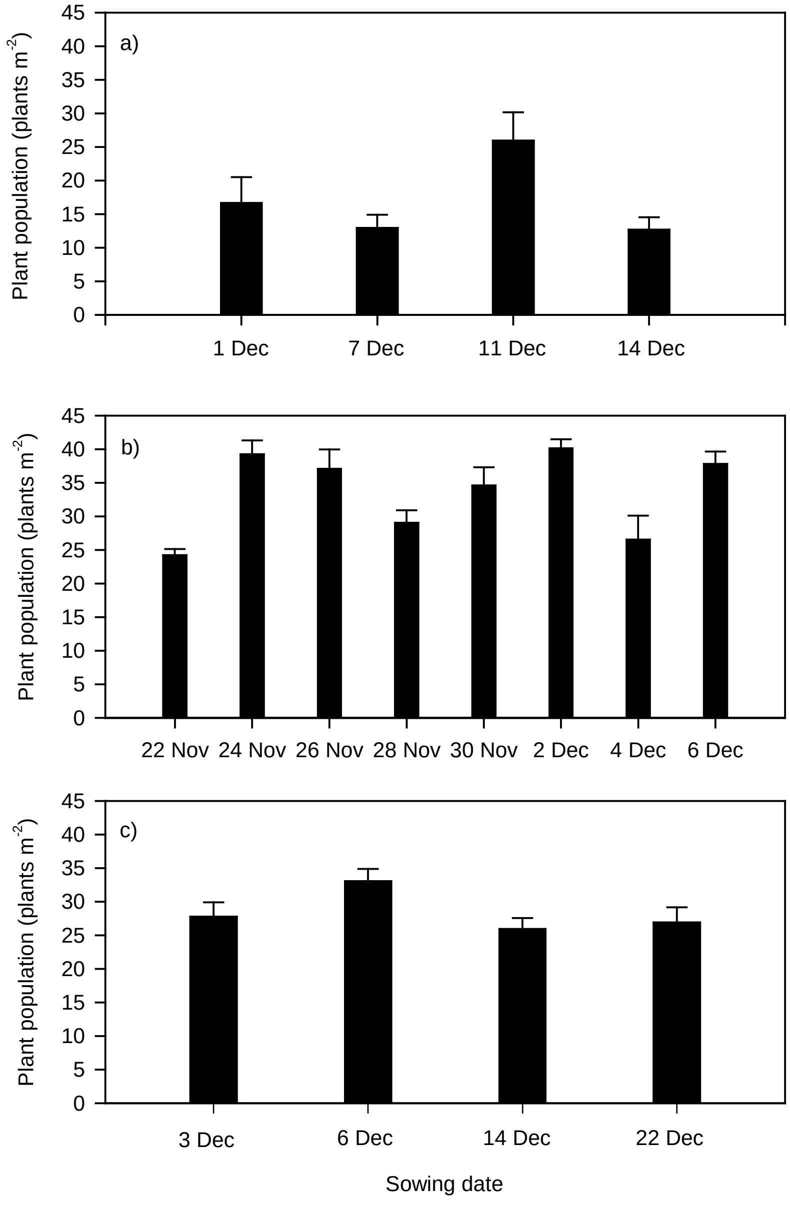

Fig. 3. The plant population (plants m^{-2}) of chickpea at emergence for: a) 2007-08 trial; b) 2008-09 trial; and c) 2009-10 trial. Error bars indicate 1 standard error.

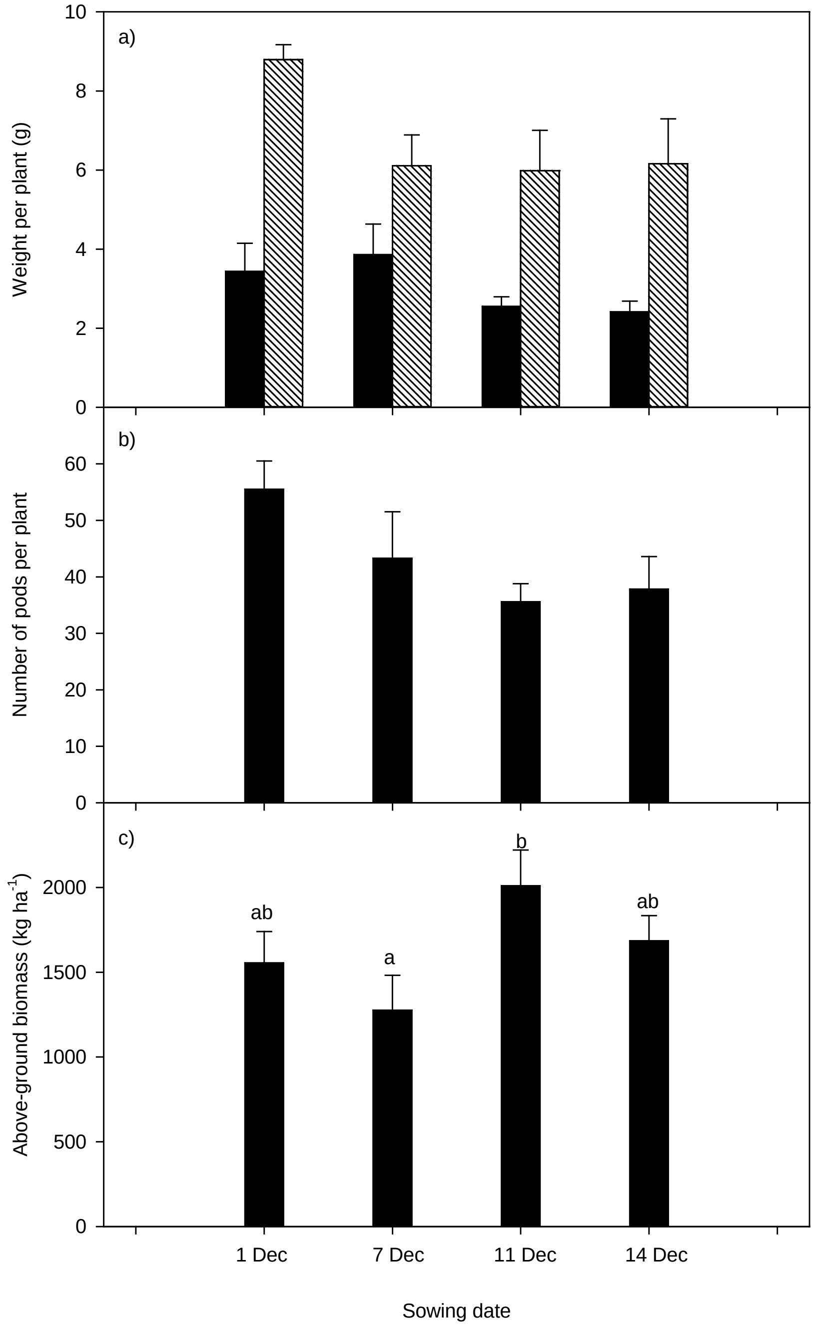

Fig. 4. The crop growth of the 2007-08 trial, a) the weight per plant (g) at flowering (full bar) and harvest (hatched bar), b) the pod number per plant at harvest, and c) above-ground biomass (kg ha^{-1}) at harvest for each sowing date. All weights reported are air-dry plant material. Above-ground biomass (kg ha^{-1}) with identical letters are not significantly different at $P < 0.05$. Error bars indicate 1 standard error.

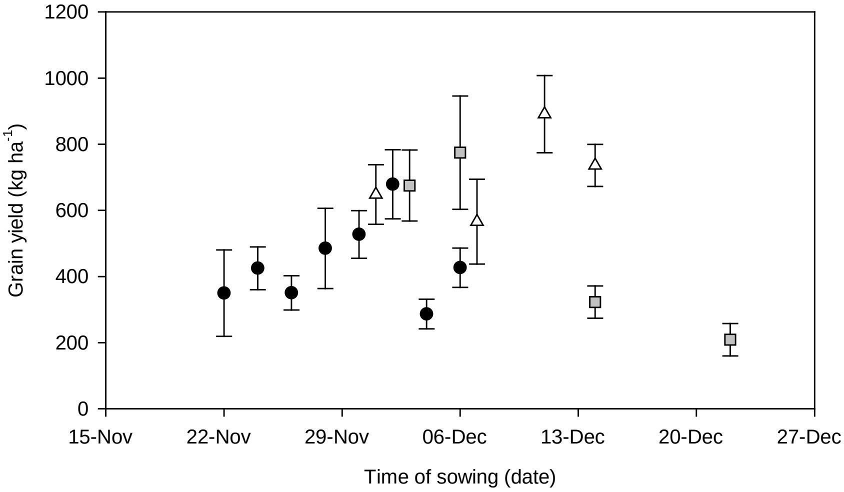

Fig. 5. The grain yield (kg ha^{-1}) for the different sowing dates over the three seasons (2007-08 Δ; 2008-09 ●; 2009-10 ■). All weights reported are air-dry plant material. Error bars indicate ± 1 standard error.

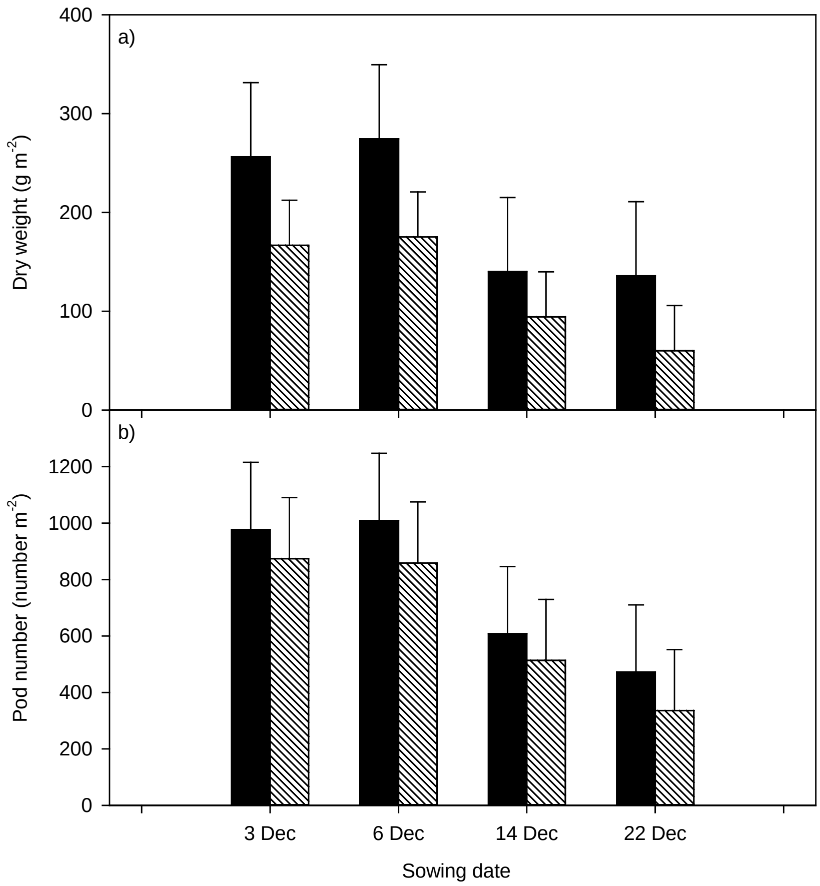

Fig. 6. The crop growth at harvest of the 2009-10 trial, a) the above-ground biomass (g m^{-2}) (filled bar) and pod weight (g m^{-2}) (hatched bar) of the quadrats, and b) the number of total pods (number m^{-2}) (filled bar) and filled pods (hatched bar) of the quadrats. All weights reported are air-dry plant material. Error bars indicate 1 least significant difference (l.s.d.) at $P < 0.05$.