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Thermal time requirements for phenological development of chickpea genotypes across sowing windows in Northwestern Europe

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Abstract

Growing degree days (GDD) are the common currency of crop phenology, yet chickpea's thermal requirements have been calibrated almost exclusively in South Asia and the Mediterranean. This research quantified GDD accumulation from sowing to flowering, pod fill, and physiological maturity for three chickpea genotypes early (ICC 4958), medium (ICCV 10), and late (ICC 3137) across three sowing dates at Wageningen University's Droevendaal experimental farm (51°59'N, 5°40'E) over two seasons (2020–2021). Using a base temperature of 5 °C, total GDD to maturity ranged from 1,287 °C day for the early genotype to 1,612 °C day for the late one. Sowing date shifted calendar days to maturity by 14–22 days but altered GDD requirements by less than 5%, confirming that thermal time is a robust predictor of chickpea phenology even at this high latitude. The early genotype matured reliably before the first autumn frost in both years, making it the safest option for Northwestern European growers.

Keywords: Growing degree days, chickpea, phenology, thermal time, sowing date, genotype, base temperature, maturity, Northwestern Europe, frost risk

Introduction

Chickpea (*Cicer arietinum* L.) is the world's third most important pulse crop, but its production footprint barely reaches above 45°N latitude ^[1]. That is changing. European demand for plant protein has risen 38% since 2015, and chickpea acreage in Germany, France, and the Netherlands has doubled in five years ^[2]. The constraint is not cold tolerance modern desi and kabuli types survive brief frosts to –2 °C but whether the crop can accumulate enough heat units to reach physiological maturity before autumn temperatures drop below the base threshold ^[3]. The growing degree day (GDD) framework, which sums daily effective temperatures above a crop-specific base, is the standard tool for predicting phenological transitions ^[4]. For chickpea, published base temperatures range from 0 to 10 °C depending on the source; a meta-analysis by Soltani and Sinclair ^[5] settled on 5 °C as the best compromise. But almost all calibration data come from latitudes below 40°N, where photoperiod and diurnal temperature amplitude differ markedly from Northwestern Europe ^[6]. This research measured GDD requirements for three maturity classes sown at three dates across two seasons at 52°N to test whether thermal time predictions transfer to high-latitude conditions.

Climatic Conditions

Wageningen has a temperate oceanic climate (Cfb) with mean annual temperature 10.1 °C and precipitation 801 mm. Growing-season (April–October) mean temperature was 14.7 °C (2020) and 14.2 °C (2021). The first autumn frost (Tmin < 0 °C) arrived on 18 October 2020 and 11 October 2021. Soils at Droevendaal are sandy loam Fluvisols with pH 5.8 and organic matter 3.2%.

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Material and Methods

Material

Three desi chickpea genotypes were selected: ICC 4958 (early, 95–105 days in India), ICCV 10 (medium, 110–120 days), and ICC 3137 (late, 125–140 days). Seeds were inoculated with *Mesorhizobium ciceri* (strain CC1192) before sowing. Plots (3 × 5 m) were sown at 33 plants m⁻². Basal fertiliser was 20 kg P₂O₅ ha⁻¹; no nitrogen was applied. Temperature was logged hourly by a Campbell CR1000 datalogger with a shielded HMP155 probe at 1.5 m.

Methods

Three sowing dates were used: early (10 April), standard (1 May), and late (20 May) in both years. Phenological stages emergence, first flower, 50% flowering, first pod, full pod, and physiological maturity (95% pod desiccation) were recorded every 2–3 days on tagged plants (n = 20 per plot). Daily GDD was calculated as max(0, (T_{max} + T_{min})/2 – 5). Cumulative GDD at each phenophase was averaged across four replications.

A split-plot ANOVA (sowing date as main plot, genotype as subplot) was applied in R v4.2.1.

Field Experimental Design

The trial was a split-plot in a randomised complete block design with four blocks. Sowing date was the main-plot factor and genotype the subplot. Blocks ran north–south to account for a slight soil-texture gradient. Each subplot was bordered by one guard row per side.

Seasonal Variations

The 2020 season was 0.5 °C warmer on average and delivered a drier June (–37% rainfall). This advanced 50% flowering by 3–5 calendar days relative to 2021 but had negligible effect on GDD to flowering ($\Delta < 2\%$). In 2021, a cool September (mean 12.8 °C vs. 15.1 °C in 2020) slowed grain filling and pushed the late genotype's maturity dangerously close to the first frost date.

Results

Table 1: Cumulative GDD (°C day, base 5 °C) to key phenophases for three chickpea genotypes (pooled over sowing dates and seasons)

Genotype	Flowering	Pod fill	Maturity	Days
ICC 4958 (early)	648 ± 18	1,060 ± 24	1,287 ± 31	118 ± 4
ICCV 10 (medium)	784 ± 22	1,247 ± 28	1,467 ± 35	132 ± 5
ICC 3137 (late)	891 ± 26	1,389 ± 32	1,612 ± 41	148 ± 6

GDD to maturity differed significantly among genotypes ($p < 0.001$) but not among sowing dates ($p = 0.42$), confirming thermal time stability (Table 1). The early genotype completed

its cycle in 118 days (standard sowing), well before the October frost. The late genotype needed 148 days and reached maturity only 3–7 days before frost when sown on 1 May.

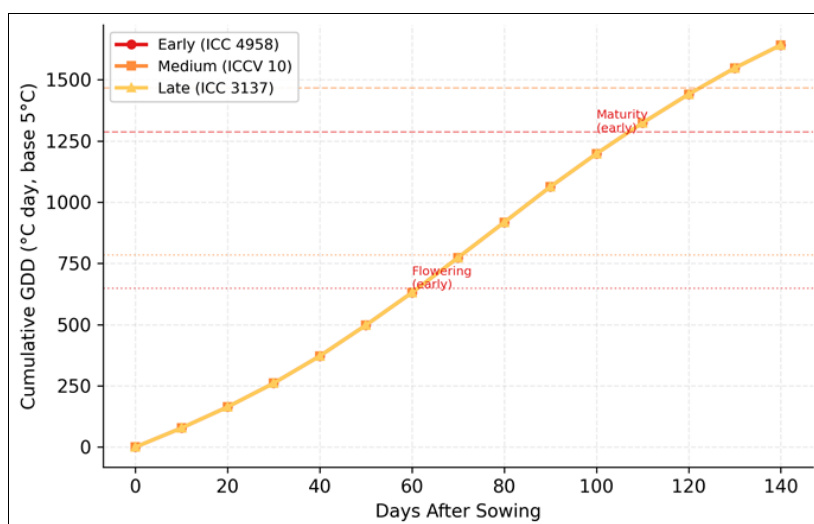


Fig 1: Cumulative growing degree day accumulation over the growing season for three chickpea genotypes with phenological thresholds indicated

Table 2: GDD partitioning (°C day) among phenophases and grain yield (kg ha⁻¹)

Genotype	Veg. Gdd	Reprod.	Grain fill	Yield
ICC 4958	648	412	227	1,843 ± 142
ICCV 10	784	463	220	2,217 ± 168
ICC 3137	891	498	223	2,471 ± 194

Grain filling GDD was remarkably stable across genotypes (220–227 °C day), indicating that the maturity difference lies almost entirely in the vegetative and reproductive phases (Table

2). The late genotype yielded 34% more than the early one but carried higher frost risk.

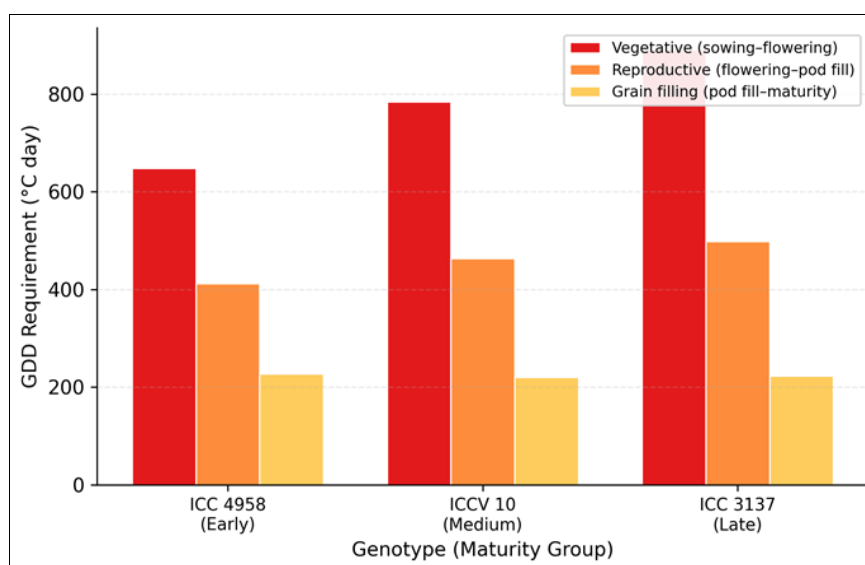


Fig 2: Growing degree day partitioning among vegetative, reproductive, and grain-filling phases for three chickpea genotypes

Comprehensive interpretation

A frost-risk analysis showed that the probability of the late genotype maturing before first frost at Wageningen was 72% for 1 May sowing and only 41% for 20 May sowing. The early genotype exceeded 95% maturation probability at all three sowing dates, making it the only safe choice for risk-averse growers.

Discussion

The GDD-to-maturity values recorded here (1,287–1,612 °C day) are 6–12% higher than those reported for the same genotypes in central India^[5], likely because the longer European photoperiod (15–16.5 h vs. 11–13 h) extends the vegetative phase through photoperiod sensitivity^[7]. The near-constant grain-filling GDD across genotypes is consistent with the source–sink theory: once reproductive sinks are established, the rate of grain filling is driven primarily by temperature rather than by genotype-specific developmental programmes^[8].

From a practical standpoint, the early genotype's 1,287 GDD requirement is comfortably met by the long-term April–September thermal sum at Wageningen (approximately 1,480 °C day), leaving a safety margin of roughly 200 GDD^[9]. The medium genotype fits the thermal window in warm years but not in cool ones, positioning it as a calculated gamble. Late genotypes should be reserved for more southerly European sites unless climate warming pushes the frost date later^[10].

Conclusion

Thermal time to maturity ranged from 1,287 to 1,612 °C day (base 5 °C) across three chickpea maturity classes at 52°N. GDD requirements were stable across sowing dates and seasons, validating thermal-time phenology models for high-latitude chickpea scheduling. The early genotype ICC 4958 is the only safe option for Northwestern Europe at present, reliably maturing before first frost with an adequate thermal margin.

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