agrometeoros
REVISTA DA SOCIEDADE BRASILEIRA DE AGROMETEOROLOGIA

ISSN 2526-7043 www.sbagro.org.br DOI: http://dx.doi.org/10.31062/agrom.v30.e027129

# Accumulated degree-days to reach the main plant developmental stages of irrigated rice cultivars

**Silvio Steinmetz[1(*)], Ariano Martins de Magalhães Júnior[1], Paulo Ricardo Reis Fagundes[1], Santiago Vianna Cuadra[2] and Ivan Rodrigues de Almeida[2]**

[1]Embrapa Clima Temperado. Rodovia BR 392, km 78, Caixa Postal 403, CEP 96.010-971 Pelotas, RS, Brazil.
E-mails: silvio.steinmetz@embrapa.br, ariano.martins@embrapa.br and paulo.fagundes@embrapa.br
[2]Embrapa Agricultura Digital. Av. Dr. André Tosello, 209 – Cidade Universitária, CEP 13083-866 Campinas, SP, Brazil.
E-mails: santiago.cuadra@embrapa.br and ivan.almeida@embrapa.br
[(*)]Correponding author.

ARTICLE INFO

**Article history:**
Received 9 September 2022
Accepted 29 November 2022

**Index terms:**
*Oryza sativa* L
thermal time
phenology

ABSTRACT

The objective of this study was to determine the accumulated degree-days (DD) to reach six plant developmental stages (PDS) of irrigated rice cultivars. Field experiments were carried out at the Estação Experimental Terras Baixas (ETB) of Embrapa Clima Temperado, located in the municipality of Capão do Leão, State of Rio Grande do Sul, Brazil, during 12 crop seasons, using six sowing dates in each. Ten plants of each cultivar were tagged and had each of the PDS monitored throughout the crop cycle. The DD (°C day) were calculated as the sum of the daily values resulting from the difference between mean air temperature (Tm) and the minimal base temperature (Tb = 11 °C), from the emergence until the date of each PDS. The results indicated that the DD to reach anthesis (R4) represented, in the average, about 77% of the total cycle (R9), ranging from 73% for IRGA 421 to 91% for Epagri 109. The vegetative period (from E-emergence to R1) is the one with the highest average DD value, around 48% of the total cycle, presenting also the largest differences between cultivars when compared to the reproductive period 1 (R1-R4) and the reproductive period 2 (R4-R9).



## Introduction

The State of Rio Grande do Sul (RS) is the largest producer of irrigated rice in Brazil, having contributed, in the growing seasons 2017/18, 2018/19 and 2019/20, with about 70% of national production (IBGE, 2020). Although the average grain yield is relatively high (7.7 t ha$^{-1}$), it is believed that it may be even higher if some aspects related to crop management are improved, reducing the yield gap indicated by Ribas et al. (2020). For this, it is important that the time of application of a particular cultural practice, such as topdressing nitrogen fertilization, water management, control of insect pests, diseases, or the time of harvest, is carried out at the right time, considering plant developmental stage (PDS), as recommended by the South-Brazilian Society of Irrigated Rice - Sosbai (Reunião, 2018).

The problem is that the occurrence of these stages, es-

pecially panicle differentiation (R1), is variable because it is dependent on temperature (Stansel, 1975; Wilson Jr. et al., 2015). For this reason, it is preferable to express the R1 stage and the other PDS through degree-days (DD), or thermal units (TU), instead of the number of days in the calendar (Streck et al., 2006a; Steinmetz et al., 2009a; 2013b).

For this reason, a software called PlanejArroz (http://planejarroz.cpact.embrapa.br) was developed to estimate the date of occurrence of six PDS, of 41 cultivars, aiming at crop management (Steinmetz et al. 2020; 2021b). As a support to this software, it is important to determine, under field conditions, the accumulated degree-days required to reach the main PDS of the new cultivars released to the market (Steinmetz et al. 2009b; 2017; 2021a).

Knowing the time of occurrence of critical subperiods of the plant development to certain abiotic stresses, such as low or high air temperatures, for example, can also be useful to: minimize the effect of harmful low air temperatures by raising the water depth between the flag leaf collar formation (R2) until the beginning of anthesis (R4) to increase its thermoregulatory effect (Reunião, 2018); evaluate the influence of high air temperatures on spikelet sterility or grain yield (Prasad et al., 2006); establish the relationship between low air temperatures and grain yield (Steinmetz et al., 2013a; Talla et al., 2017). The subperiod from R2 to R4 is also the most indicated for controlling plant diseases such as blast (*Pyricularia oryzae* (Cavara); *Magnaporthe oryzae* B. Couch – forma perfeita) (Reunião, 2018)".

In general, the date of occurrence of the main PDS is determined in field experiments, at different sowing times, using a phenological scale (Watson et al., 2004; Streck et al., 2006a; Steinmetz et al., 2017). It is recommended that the degree-days necessary to reach each of the PDS be determined experimentally in one or more localities, but aiming to extrapolate the results to other areas as indicate the experiences with the DD50 program in the United States (Wilson Jr. et al., 2015), and with PlanejArroz in the State of Rio Grande do Sul, Brazil (Steinmetz et al., 2020; 2021b).

The objective of this study was to determine the accumulated degree-days (DD) needed to reach six plant developmental stages (PDS) of irrigated rice cultivars.

## Material and Methods

The field experiments were carried out at the area of the Estação Experimental Terras Baixas (ETB) of Embrapa Clima Temperado, in municipality of Capão do Leão, RS, Brazil (latitude 31° 52′ S; longitude 52° 21' W and altitude 13 m), during a period of 12 crop seasons (2004/2005 - 2015/2016). The local climate, according to the Köppen classification, is of the Cfa type, which corresponds to the humid subtropical, with hot summers and without a defined dry season (Wrege et al., 2011). The soil in the experimental area is classified as a typical eutrophic Haplossolo Haplico (Santos et al., 2006). The plots were 5m long and 1.58m wide, consisting of 9 lines spaced by 17.5cm. The basic and topdressing fertilizations and other cultural treatments followed the recommendations of Sosbai (Reunião, 2003) for the 2004/2005 crop season, and the current Sosbai indications for the other crop seasons. The date of emergence was considered when around 50% of the seedlings in the plot were visible above ground level.

In general, twelve cultivars and six sowing dates (from early September to mid-December) were used in each crop season. However, throughout the years, some cultivars were replaced by others, making variable the number of crop seasons for each cultivar. In this work, 34 cultivars were evaluated, involving the four cycles indicated by Sosbai (Reunião, 2018).

In order to facilitate the interpretation of the results, the cultivars were classified, according to their cycles, into seven subgroups. The numbers between parenthesis indicate the average cycle lenght, in days, according to Sosbai (Reunião, 2018) while those between brackets correspond to the number of years in which data were collected for that cultivar. The cultivars evaluated were one of Very Short cycle 1 (VS1): IRGA 421 (95) [7]; two of Very Short cycle 2 (VS2): BRS Atalanta (100) [12]; BRS Ligeirinho (95) [2]; two of Short cycle 1 (S1): BRS 6 "Chuí" (110) [5]; BRS Querência (110) [12]; eleven of Short cycle 2 (S2): BRS Pampa (118) [8]; BRS Firmeza (120) [5]; IRGA 417 (115) [9]; IRGA 422 CL (120) [3]; IRGA 423 (120) [3]; IRGA 430 (120) [1]; Avaxi CL (120) [7]; Inov CL (120) [7]; Titan CL (120) [1]; Guri Inta CL (120) [3]; Puitá Inta CL (120) [5]; nine of Medium cycle 1 (M1): BRS Pelota (125) [6]; BRSCIRAD 302 (128) [3]; BRS Sinuelo CL (130) [7]; BR-IRGA 410 (123) [4]; BR-IRGA 409 (126) [5]; IRGA 429 (124) [1]; IRGA 426 (125) [3]; IRGA 428 CL (125) [2]; Lexus CL (128) [3]; seven of Medium cycle 2 (M2): BRS 7 "Taim (130) [5]; BRS Bojuru (135) [2]; BRS Fronteira (135) [8]; IRGA 424 (132) [8]; IRGA 424 IR (133) [1]; IRGA 425 (132) [3]; IRGA 427 (136) [2]; and two of Long cycle (L): SCS BRS Tio Taka (141) [6]; Epagri 109 (142) [4]. This division into subgroups aimed to meet the needs of the GD Arroz program (Steinmetz et al., 2018) so that the dates of occurrence of the cultivars' stages could be estimated, with reasonable accuracy, from the subgroups to which they belong to. Of the 34 cultivars evaluated in this work, 28, that is 70%, are on the list of all cultivars (40) recommended by Sosbai (Reunião, 2018) for cultivation in the states of Rio Grande do Sul and Santa Catarina.

Ten plants (main stem) of each cultivar were labeled and had their development monitored throughout the cycle, each stage being characterized according to the scale proposed by Counce et al. (2000). Two to three readings

were taken per week. Average dates for each stage were obtained from the observations in the 10 plants. The stage R1 (panicle differentiation) was determined by the method described by Steinmetz et al. (2009a).

The six stages considered in this work were: V4: plant with four leaves; R1: panicle differentiation; R2: flag leaf collar formation (booting); R4: anthesis (one or more florets); R8: maturity of an isolated grain; R9: complete maturity of the panicle grains. To better characterize the phenological behavior of the cultivars, six subsequent subperiods of plant development were established (E-V4; V4-R1; R1-R2; R2-R4; R4-R8 and R8-R9). Three larger periods were also established, namely, vegetative period (E-R1), reproductive period 1 (R1-R4) and reproductive period 2 (R4-R9), respectively. The reason for the last criterion is that, before the study of Counce et al. (2000), the periods E-R1, R1-R4 and R4-R9 were considered, respectively, as vegetative, reproductive and maturation phases (Yoshida, 1981). On the scale of Counce et al. (2000), the first subperiod corresponds to the vegetative phase and the other two are part of the reproductive phase. In this study, the beginning of the reproductive period will be considered as the R1 stage and not the R0 (panicle initiation), as indicated in Counce et al. (2000).

To calculate the accumulated degree-days starting at crop emergence, the following equation was used:

$$DD = \sum_{i=1}^{n} (Tm - Tb)$$

where DD (°C day) represents the sum of the difference between the average daily air temperature (Tm) and the base temperature (Tb) of 11 °C (Infeld et al., 1998) from the emergence (i = 1) to each of the six stages (n). The Tm was obtained by the arithmetic mean between the maximum (Tx) and minimum (Tn) daily air temperatures. To calculate the Tm, the thresholds of 34 °C and 21 °C were applied to Tx and Tn, respectively (Slaton et al., 1996). This equation is also used for the calculation of degree-days by the program DD50, a modification of the original concept of growing degree-days that uses upper thresholds for the daily values of Tx and Tn so that air temperatures above these thresholds do not result in faster plant development (Slaton et al., 1996; Wilson Jr. et al., 2015). The degree-days to reach each plant stage represent the average of the six sowing times, in each crop season, and of the several crop seasons in which the cultivar was used.

The statistical comparison of the cultivars regarding the degree-days to reach the six plant stages, the six subperiods and the three periods of plant development was made using the Mood test, a non-parametric method, since the data (residues) do not present normal distribution in the linear model fitting (Siegel & Castellan Jr., 1988).

## Results and discussion

The accumulated degree-days (DD) to reach each of the six PDS varied according to the cultivar cycle (Figure 1). For most plant stages, except for V4, there was statistical difference (SD) between some cultivars, especially for those belonging to different subgroups (Table 1).

The DD to reach the R1 stage represented about 48%

**Figure 1.** Accumulated average degree-days (°C day) from emergence to the plant developmental stages V4 (plant with four leaves), R1 (panicle differentiation), R2 (booting), R4 (anthesis), R8 (beginning of ripening) and R9 (complete ripening of grains), of four irrigated rice cultivars, of Very short (IRGA 421), Short (BRS Pampa), Medium (IRGA 424 RI) and Long (Epagri 109) cycles, obtained during twelve crop seasons (2004/2005 - 2015/2016), in Capão do Leão, RS, Brazil.

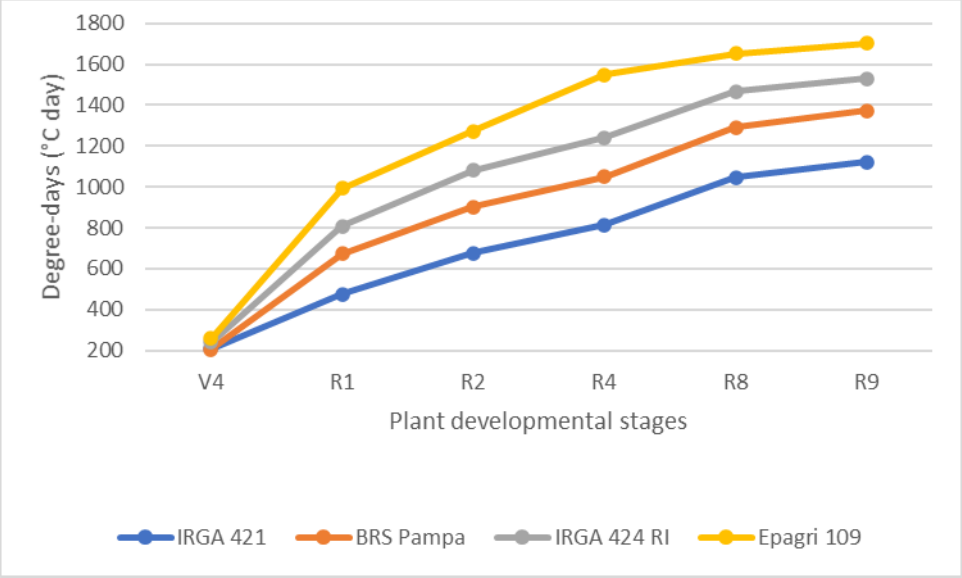

**Table 1.** Accumulated average degree-days (°C day) from emergence to each of the six plant developmental stages of 34 irrigated rice cultivars, obtained during twelve crop seasons (2004/2005 - 2015/2016), in Capão do Leão, RS, Brazil. The numbers between parenthesis indicate the average cycle of the cultivar, in days (Reunião, 2018), and between brackets the number of crop seasons in which the cultivar was evaluated.

| Cultivar (Cycle)(Nr seasons) | Subgroup | Accumulated average degree-days (°C day) from the emergence to the plant stage | | | | | |
|---|---|---|---|---|---|---|---|
| | | V4 | R1 | R2 | R4 | R8 | R9 |
| IRGA 421(95) [7] | VS1 | 210 ns | 476 f | 675 h | 816 f | 1046 i | 1122 g |
| Average (VS1) | | 210 | 476 | 675 | 816 | 1046 | 1122 |
| BRS Atalanta (100) [12] | VS2 | 211 ns | 513 f | 729 g | 890 e | 1128 h | 1215 f |
| BRS Ligeirinho (95) [2] | | 217 ns | 508 f | 749 g | 889 e | - | 1216 f |
| Average (VS2) | | 214 | 511 | 739 | 890 | 1128 | 1216 |
| BRS 6 "Chuí" (110) [5] | S1 | 185 ns | 605 e | 824 f | 993 d | 1185 g | 1298 e |
| BRS Querência (110) [(12] | | 208 ns | 625 e | 848 e | 1011 d | 1255 f | 1341 e |
| Average (S1) | | 197 | 615 | 836 | 1002 | 1220 | 1320 |
| BRS Pampa (118) [8] | S2 | 205 ns | 674 d | 903 e | 1049 d | 1291 e | 1372 d |
| BRS Firmeza (120) [5] | | 285 ns | 682 d | 889 e | 1063 d | 1227 g | 1322 e |
| IRGA 417 (115) [9] | | 201 ns | 670 d | 880 e | 1022 d | 1256 f | 1352 e |
| IRGA 422 CL (120) [3] | | 162 ns | 691 d | 900 e | 1045 d | 1281 f | 1392 d |
| IRGA 423 (120) [3] | | 234 ns | 680 d | 861 e | 1023 d | 1252 f | 1361 e |
| IRGA 430 (120) [1] | | 255 | 730 | 927 | 1109 | 1337 | 1396 |
| Avaxi CL (120) [7] | | 205 ns | 678 d | 898 e | 1060 d | 1311 e | 1410 d |
| Inov CL (120) [7] | | 201 ns | 679 d | 909 e | 1073 d | 1320 e | 1415 d |
| Titan CL (120) [1] | | 243 ns | 690 d | 885 e | 1042 d | 1310 e | 1388 d |
| Guri Inta CL (120) [3] | | 245 ns | 696 d | 919 e | 1061 d | 1315 e | 1390 d |
| Puitá Inta CL (120) [5] | | 202 ns | 703 d | 918 e | 1065 d | 1322 e | 1409 d |
| Average (S2) | | 222 | 688 | 899 | 1056 | 1293 | 1382 |
| BRS Pelota (125) [6] | M1 | 198 ns | 726 c | 962d | 1124 c | 1334 d | 1452 c |
| BRSCIRAD 302 (128) [3] | | 204 ns | 700 d | 944d | 1128 c | 1396 c | 1485 b |
| BRS Sinuelo CL (130) [7] | | 199 ns | 731 c | 940 d | 1094 c | 1348 d | 1438 c |
| BR-IRGA 410 (123) [4] | | 190 ns | 700 d | 966 d | 1129 c | 1348 d | 1444 c |
| BR-IRGA 409 (126) [5] | | 212 ns | 729 c | 955 d | 1095 c | 1332 d | 1400 c |
| IRGA 429 (124) [1] | | 263 | 770 | 1051 | 1221 | 1446 | 1509 |
| IRGA 426 (125) [3] | | 212 ns | 701 d | 936 d | 1083 d | 1326 d | 1407 d |
| IRGA 428 CL (125) [2] | | 234 ns | 739 c | 947 d | 1110 c | 1343 d | 1416 d |
| Lexus CL (128) [3] | | 217 ns | 699 d | 941 d | 1111 c | 1367 d | 1461 c |
| Average (M1) | | 214 | 722 | 960 | 1022 | 1360 | 1446 |
| BRS 7 "Taim (130) [5] | M2 | 178 ns | 732 c | 998 c | 1150 c | 1352 d | 1453 c |
| BRS Bojuru (135) [2]) | | 211 ns | 732 c | 962 d | 1075 d | - | 1437 c |
| BRS Fronteira (135) [8] | | 181 ns | 741 c | 992 c | 1135 c | 1361 d | 1445 c |
| IRGA 424 (132) [8] | | 226 ns | 760 b | 1005 c | 1162 c | 1411 c | 1458 b |
| IRGA 424 RI (133) [1] | | 239 ns | 807 | 1080 | 1242 | 1468 | 1529 |
| IRGA 425 (132) [3] | | 194 ns | 685 d | 922 e | 1076 d | 1340 d | 1412 d |
| IRGA 427 (136) [2] | | 226 ns | 792 b | 1016 c | 1178 c | 1405 c | 1470 c |
| Average (M2) | | 208 | 750 | 996 | 1145 | 1390 | 1458 |
| SCS BRS Tio Taka (141) [6] | L | 235 ns | 944 a | 1244 a | 1412 a | 1649 a | 1712 a |
| Epagri 109 (142) [4] | | 260 ns | 992 a | 1272 a | 1548 a | 1654 a | 1704 a |
| Average (L) | | 248 | 968 | 1258 | 1480 | 1652 | 1708 |

V4 = plant with 4 leaves; R1 = panicle differentiation; R2 = formation of the flag leaf collar (booting); R4 = anthesis (one or more spikelets); R8 = maturity of an isolated grain; R9 = complete maturity of the panicle grains. Plant developmental stages according to the scale of Counce et al. (2000). VS1 = Very short 1; VS2 = Very short 2; S1 = Short 1; S2 = Short 2; M1 = Medium 1; M2 = Medium 2; L = Long, according to Steinmetz et al. (2018).
Values with equal letters in the column do not differ statistically from each other by the Mood test (at 95% confidence); ns = no statistical significance

of the total cycle (R9), on average of 34 cultivars, ranging from 42% for IRGA 421 (476 over 1122 °C day) to 58% for Epagri 109 (992 over 1704 °C day) (Table 1).

These percentages are similar to those obtained previously with other cultivars (Steinmetz et al., 2009a). In the average of the cultivars the DD to reach the R4 stage represented around 77% of the total cycle (R9), varying from 73% for IRGA 421 (816 over 1122 °C day) to 91% for Epagri 109 (1548 on 1704 °C day) (Table 1). The average percentage of 34 cultivars (77%) is similar to the average value of 74% obtained by Watson et al. (2004), for twelve cultivars, in Arkansas (USA).

The date of occurrence of the R1 stage is highly influenced by temperature, and may present significant differences between cultivars, according to the sowing time, regardless of the subgroups to which they belong to. Early and late sowing tend, respectively, to lengthen and shorten the subperiod from emergence to the R1 stage (Steinmetz et al., 2009ab; Singh et al., 2012). These differences tend to decrease when expressed in DD (Steinmetz et al., 2009a). The photoperiod is another factor that can interfere with the duration of this subperiod, depending on the sensitivity of the cultivar and the sowing time (Yoshida, 1981; Streck et al., 2006b). The DD values in Table 1, to reach the R1 stage, indicate only the differences between the cultivars, as they represent the averages of six sowing times, of 12 or less growing seasons.

The sowing time used in the experiments can be one of the explanations for the differences in DD of this and other studies with irrigated rice in the State of Rio Grande do Sul indicated in the literature. Streck et al. (2006a), for example, for the plant cycle (E-R9) of the cultivars IRGA 417 and BR-IRGA 409 found the values of 1681.7 °C day and 1903.4 °C day, respectively. These values are higher than the 1352 °C day and 1400 °C day, to reach the R9 stage, respectively, of the cultivars IRGA 417 and BR-IRGA 409. It is believed that the late sowing times, in January and even in March, be the reason for the highest DD values found by these authors. In these late sowings, another factor that may have contributed to increase in DD values is the influence of the photoperiod in increasing the cycle of these cultivars, as indicated by the results of Streck et al. (2006b).

Likewise, the delay in the start of sowing by about one month (beginning of October instead of the beginning of September), may explain the lower value (638 °C day) to reach the R1 stage of the medium cycle cultivars, indicated by Infeld et al. (1998), compared with the Medium 1 subgroup of this study (722 °C day), to which the cultivars BR-IRGA 409 and BR-IRGA 410 used in the referred work belong to. In addition to the sowing time, it is likely that part of this difference can be attributed to the other cultivars that belong to the M1 subgroup of this work, as well as those in the group characterized as medium cycle in the work by Infeld et al. (1998).

Of the six subperiods evaluated, the only one that showed statistical diferences between cultivars, especially for those belonging to different subgroups, was between the four-leaf stage and the panicle differentiation (V4-R1) (Table 2). In the other subperiods, there was no statistical significance. Figure 2 illustrates this behavior for four cultivars of different cycles.

When the mean of all cultivars was considered, the

**Figure 2.** Accumulated average degree-days (°C day) for subperiods E-V4 (from emergence to the stage of four leaves), V4-R1 (from V4 to panicle differentiation), R1-R2 (from R1 to booting), R2-R4 (from booting to anthesis), R4-R8 (from anthesis to the beginning of maturation), R8-R9 (from the beginning of maturation to the complete ripening of grains), of four irrigated rice cultivars, of Very short (IRGA 421), Short (BRS Pampa), Medium (IRGA 424 RI) and Long (Epagri 109) cycles, obtained during twelve crop seasons (2004/2005 - 2015/2016), in Capão do Leão, RS, Brazil.

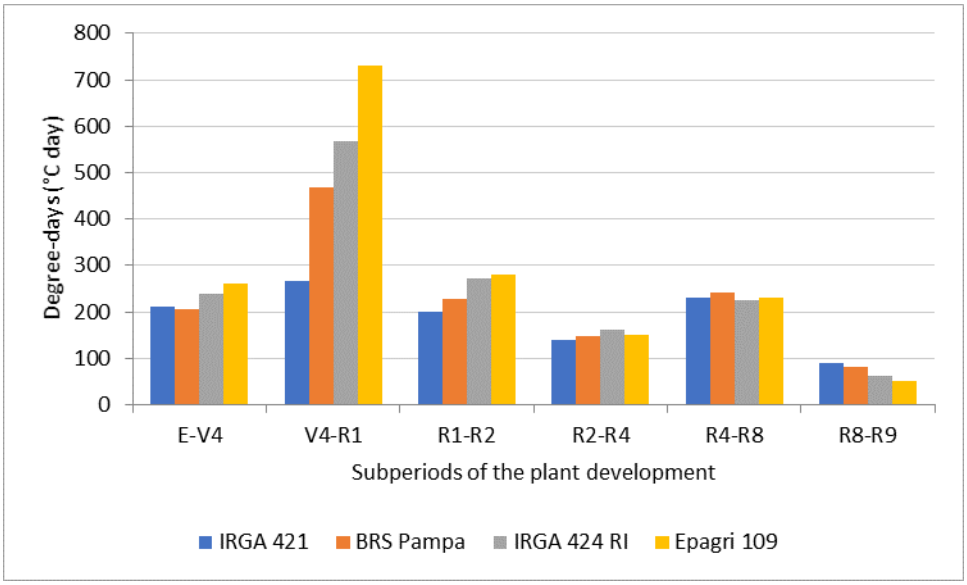

**Table 2.** Accumulated average degree-days (°C day) between plant developmental stages of 34 irrigated rice cultivars, obtained during twelve crop seasons (2004/2005 - 2015/2016), in Capão do Leão, RS, Brazil. The numbers between parenthesis indicate the average cycle of the cultivar, in days (Reunião, 2018), and between brackets the number of crop seasons in which the cultivar was evaluated.

| Cultivar | Subgroup | Accumulated average degree-days (°C day) between plant developmental stages | | | | | |
|---|---|---|---|---|---|---|---|
| (Cycle)(Nr seasons) | | E-V4 | V4-R1 | R1-R2 | R2-R4 | R4-R8 | R8-R9 |
| IRGA 421(95) [7] | VS1 | 210 ns | 267 e | 199 ns | 140 ns | 230 ns | 89 ns |
| Average (VS1) | | 210 | 267 | 199 | 140 | 230 | 89 |
| BRS Atalanta (100) [12] | VS2 | 211 ns | 302 e | 216 ns | 161 ns | 241 ns | 87 ns |
| BRS Ligeirinho (95) [2] | | 217 ns | 292 e | 241 ns | 140 ns | - | - |
| Average (VS2) | | 214 | 297 | 229 | 151 | 241 | 87 |
| BRS 6 "Chuí" (110) [5] | S1 | 165 ns | 420d | 219 ns | 169 ns | 209 ns | 105 ns |
| BRS Querência (110) [12] | | 208ns | 418 d | 222 ns | 163 ns | 247 ns | 90 ns |
| Average (S1) | | 187 | 419 | 221 | 166 | 228 | 98 |
| BRS Pampa (118) [8] | S2 | 205 ns | 468 c | 229 ns | 147 ns | 241 ns | 81 ns |
| BRS Firmeza (120) [5] | | 285 ns | 397 d | 207 ns | 174 ns | 215 ns | 94 ns |
| IRGA 417 (115) [9] | | 201 ns | 468 c | 210 ns | 142 ns | 234 ns | 96 ns |
| IRGA 422 CL (120) [3] | | 162 ns | 529 b | 209 ns | 145 ns | 236 ns | 112 ns |
| IRGA 423 (120) [3] | | 234 ns | 446 c | 181 ns | 162 ns | 229 ns | 109 ns |
| IRGA 430 (120) [1] | | 255 | 475 | 197 | 183 | 228 | 58 |
| Avaxi CL (120) [7] | | 205 ns | 473 c | 220 ns | 162 ns | 255 ns | 95 ns |
| Inov CL (120) [7] | | 201 ns | 478 c | 230 ns | 164 ns | 248 ns | 93 ns |
| Titan CL (120) [1] | | 243 ns | 446 c | 195ns | 157 ns | 268 ns | 78 ns |
| Guri Inta CL (120) [3] | | 202 ns | 501 c | 215 ns | 148 ns | 257 ns | 87 ns |
| Puitá Inta CL (120) [5] | | 245 ns | 450 c | 223 ns | 142 ns | 254 ns | 75 ns |
| Average (S2) | | 222 | 466 | 211 | 157 | 242 | 89 |
| BRS Pelota (125) [6] | M1 | 198 ns | 528 b | 236 ns | 162 ns | 228 ns | 118 ns |
| BRSCIRAD 302 (128) [3] | | 204 ns | 496 c | 245 ns | 184 ns | 268 ns | 89 ns |
| BRS Sinuelo CL (130) [7] | | 199 ns | 532 b | 209 ns | 154 ns | 254 ns | 90 ns |
| BR-IRGA 410 (123) [4] | | 190 ns | 509 c | 266 ns | 163 ns | 225 ns | 105 ns |
| BR-IRGA 409 (126) [5] | | 212 ns | 509 c | 231 ns | 142 ns | 236 ns | 120 ns |
| IRGA 429 (124) [1] | | 263 | 507 | 281 | 170 | 225 | 63 |
| IRGA 426 (125) [3] | | 212 ns | 489 c | 235 ns | 147 ns | 243 ns | 80 ns |
| IRGA 428 CL (125) [2] | | 234 ns | 506 c | 208 ns | 163 ns | 233 ns | 73 ns |
| Lexus CL (128) [3] | | 217 ns | 482 c | 242 ns | 170 ns | 256 ns | 94 ns |
| Average (M1) | | 214 | 506 | 239 | 162 | 241 | 92 |
| BRS 7 "Taim (130) [5] | M2 | 178 ns | 554 b | 265 ns | 152 ns | 219 ns | 99 ns |
| BRS Bojuru (135) [2] | | 211 ns | 521 b | 231 ns | 113 ns | - | - |
| BRS Fronteira (135) [8] | | 181 ns | 560 b | 251 ns | 143 ns | 234 ns | 87 ns |
| IRGA 424 (132) [8] | | 226 ns | 534 b | 245 ns | 158 ns | 248 ns | 78 ns |
| IRGA 424 RI (133) [1] | | 239 | 568 | 273 | 162 | 226 | 61 ns |
| IRGA 425 (132) [3] | | 194 ns | 491 c | 237 ns | 153 ns | 265 ns | 72ns |
| IRGA 427 (136) [2] | | 226 ns | 566 b | 225 ns | 162 ns | 227 ns | 65 ns |
| Average (M2) | | 208 | 542 | 247 | 149 | 237 | 77 |
| SCS BRS Tio Taka (141) [6] | L | 235 ns | 709 a | 300 ns | 167 ns | 237 ns | 63 ns |
| Epagri 109 (142) [4] | | 260 ns | 732 a | 280 ns | 151 ns | 231 ns | 50 ns |
| Average (L) | | 248 | 721 | 290 | 159 | 234 | 57 |

E-V4=from emergence to the stage of 4 leaves; V4-R1= from the stage of 4 leaves to panicle differentiation; R1-R2= from panicle differentiation to the formation of the flag leaf collar (booting); R2-R4= from booting to anthesis (one or more florets); R4-R8= from anthesis to maturity of an isolated grain; R8-R9= from the maturity of an isolated grain to the complete maturity of the panicle grains. Plant developmental stages according to the scale of Counce et al. (2000). VS1 = Very short 1; VS2 = Very short 2; S1 = Short 1; S2 = Short 2; M1 = Medium 1; M2 = Medium 2; L = Long, according to Steinmetz et al. (2018).

Values with equal letters in the column do not differ statistically from each other by the Mood test (at 95% confidence); ns = no statistical significance.

subperiod V4-R1 was the one with the highest DD value (460 °C day), followed by the subperiods R4-R8 (236 °C day) and R1-R2 (234 °C day). Proportionally, these three subperiods represented around 33%, 17% and 17%, respectively, of the DD of the entire cycle (1379 °C day), that is, from the emergence to the complete maturation of the grains (E-R9). These results are in line with those obtained previously by Steinmetz et al. (2009b), for a group of 16 cultivars, of three maturation groups. The value of 17%, relative to the average DD of the cultivars for the subperiod R4-R8 in relation to the DD of the total cycle of this study, is equal to the 17% found by Watson et al. (2004) when evaluating the DD of twelve irrigated rice cultivars in the State of Arkansas (USA).

There was statistical difference (SD) between cultivars for the three periods analyzed, that is, vegetative (E-R1), reproductive 1 (R1-R4) and reproductive 2 (R4-R9) (Table 3). However, SD were more accentuated in the periods vegetative and reproductive 1, probably because these are the periods responsible for the most expressive parts of the total cycle of cultivars, as indicated by the results obtained previously by Steinmetz et al. (2009b). Figure 3 illustrates this behavior, using four cultivars of different cycles.

Considering the average of the cultivars, the E-R1 period was the one with the highest DD value (676 °C day), followed by the R1-R4 (338 °C day) and R4-R9 (317 °C day) periods. Proportionally, these three periods represented around 49%, 28% and 23%, respectively, of the DD of the entire cycle (1379 °C day), that is, from the emergence to the complete maturation of the grains (E-R9). These results are in line with those previously indicated by Steinmetz et al. (2009b), for a group of 16 cultivars. The value of 23% relative to the average DD of the cultivars for the R4-R9 period, in relation to the DD of the entire cycle of this study, is similar to the 26% found by Watson et al. (2004), for twelve cultivars, in the State of Arkansas (USA).

One of the difficulties to compare the results of this study with those obtained by other authors concerning the length of the vegetative period, which in this work was from emergence to panicle differentiation (E-R1), while other authors assumed that it was from emergence to booting (E-R2) (Watson et al., 2004; Streck et al., 2006a). It is likely that this is because the R2 stage is easily identified in the field, besides avoiding destructive sampling of plants as occurs to determine the R1 stage (Stansel, 1975; Steinmetz et al., 2009a). The problem is that the difference between the stages R1 and R2 can be of great magnitude. In this study it varied between 15 and 26 days, respectively, for the cultivars IRGA 421 and Epagri 109.

Thus, when there is a need to determine the length of the vegetative period with greater accuracy, aiming at some management practice, it is recommended to use a method that allows determining the stage of panicle differentiation (R1) and, if possible, the panicle initiation (PI). This is the case, for example, with nitrogen topdressing (NTD), which should be applied at the panicle initiation stage (R0) according to Sosbai (Reunião, 2018).

As the stage R0 is difficult to be visualized directly on the plant, under field conditions, Steinmetz et al. (2014; 2018) suggest using the degree-day method to estimate the R1 stage, visible to the naked eye, which occurs, on

**Figure 3.** Accumulated average degree-days (°C day) for the vegetative period (from emergence to panicle differentiation: E-R1), reproductive 1 (from panicle differentiation to anthesis: R1-R4) and reproductive 2 (from anthesis to complete grain maturation: R4-R9), of four irrigated rice cultivars, of Very short (IRGA 421), Short (BRS Pampa), Medium (IRGA 424 RI) and Long (Epagri 109) cycles, obtained during twelve crop seasons (2004/2005 - 2015/2016), in Capão do Leão, RS, Brazil.

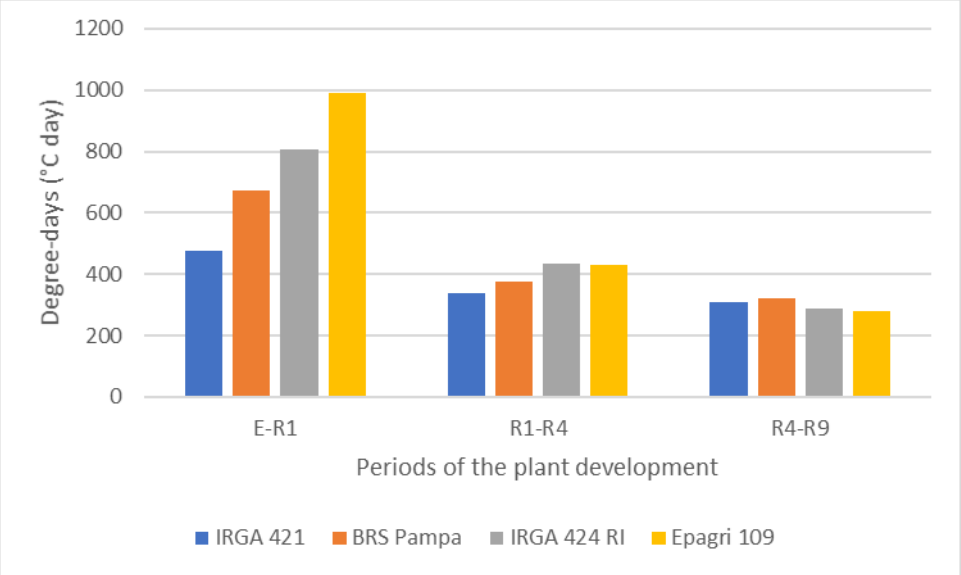

**Table 3.** Accumulated average degree-days (°C day) of three periods of the plant cycle, of 34 irrigated rice cultivars, obtained during twelve growth seasons (2004/2005 - 2015/2016), in Capão do Leão, RS, Brazil. The numbers in parentheses indicate the average cycle of the cultivar, in days (Reunião, 2018), and in brackets the number of growth seasons in which the cultivar was evaluated.

| Cultivar (Cycle)(Nr seasons) | Subgroup | Accumulated average degree-days (°C day) in the periods | | |
|---|---|---|---|---|
| | | E-R1 (VP) | R1-R4 (RP1) | R4-R9 (RP2) |
| IRGA 421(95) [7] | VS1 | 476 f | 339 c | 307 b |
| Average (VS1) | | 476 | 339 | 307 |
| BRS Atalanta (100) [12] | VS2 | 513 f | 377 b | 325 a |
| BRS Ligeirinho (95) [2] | | 508 f | 381 b | 327 a |
| Average (VS1) | | 511 | 379 | 326 |
| BRS 6 "Chuí" (110) [5] | S1 | 605 e | 388 b | 305 b |
| BRS Querência (110) [12] | | 625 e | 386 b | 330 a |
| Average (S1) | | 615 | 387 | 318 |
| BRS Pampa (118) [8] | S2 | 674 d | 376 b | 323 a |
| BRS Firmeza(120) [5] | | 682 d | 382 b | 259 b |
| IRGA 417 (115) [9] | | 670 d | 352 c | 330 a |
| IRGA 422 CL (120) [3] | | 691 d | 354 c | 347 a |
| IRGA 423 (120) [3] | | 680 d | 343 c | 338 a |
| IRGA 430 (120 ) [1] | | 730 | 380 | 286 |
| Avaxi CL (120) [7] | | 678 d | 382 b | 350 a |
| Inov CL (120) [7] | | 679 d | 394 b | 342 a |
| Titan CL (120) [1] | | 690 d | 353 c | 346 a |
| Guri Inta CL (120) [3] | | 696 d | 366 c | 328 a |
| Puitá Inta CL (120) [5] | | 703 d | 362 c | 344 a |
| Average (S2) | | 688 | 368 | 327 |
| BRS Pelota (125) [6] | M1 | 726 c | 398 b | 328 a |
| BRSCIRAD 302 (128) [3] | | 700 d | 429 a | 357 a |
| BRS Sinuelo CL (130) [7] | | 731 c | 354 c | 376 a |
| BR-IRGA 410 (123) [4] | | 700 d | 429 a | 316 b |
| BR-IRGA 409 (126) [5] | | 720 c | 373 b | 357 a |
| IRGA 429 (124) [1] | | 770 | 451 | 288 |
| IRGA 426 (125) [3] | | 701 d | 382 b | 323 a |
| IRGA 428 CL (125) [2] | | 739 c | 371 b | 306 b |
| Lexus CL (128) [3] | | 699 d | 412 a | 350 a |
| Average (M1) | | 721 | 400 | 333 |
| BRS 7 "Taim (130) [5] | M2 | 732 c | 417 a | 303 b |
| BRS Bojuru (135) [2] | | 732 c | 344 c | 362 a |
| BRS Fronteira (135) [8] | | 741 c | 394 b | 310 b |
| IRGA 424 (132) [8] | | 760 b | 402 b | 326 a |
| IRGA 424 RI (133) [1] | | 807 | 435 | 287 |
| IRGA 425 (132) [3] | | 685 d | 391 b | 336 a |
| IRGA 427 (136) [2] | | 792 b | 387 b | 292b |
| Average (M2) | | 750 | 396 | 317 |
| SCS BRS Tio Taka (141) [6] | L | 944 a | 468 a | 300 b |
| Epagri 109 (142) [4] | | 992 a | 431 a | 281 b |
| Average (L) | | 968 | 450 | 291 |

E-R1= from the emergence to panicle differentiation (Vegetative Period - VP); R1-R4= from the panicle differentiation to anthesis (Reproductive Period 1 - RP1); R4-R9= from the anthesis to the complete maturity of the panicle grains (Reproductive Period 2 - RP2). Plant developmental stages according to the scale of Counce et al. (2000). VS1 = Very short 1; VS2 = Very short 2; S1 = Short 1; S2 = Short 2; M1 = Medium 1; M2 = Medium 2; L = Long, according to Steinmetz et al. (2018).
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average, four days after the R0 stage (Carli, 2016). In this way, it is possible to plan for NTD to be performed, at least four days before the estimated date of R1, so that nitrogen is available to plants at the R0 stage, as recommended by Sosbai (Reunião, 2018).

The results obtained in this study are an improvement over those obtained previously (Streck et al., 2006a; Steinmetz et al. 2009b; 2021a) because a greater number of cultivars (34) were evaluated, being most of them (around 70%) recommended for cultivation in the states of Rio Grande do Sul and Santa Catarina (Reunião, 2018). These results can be useful if one wants to use the DD of each cultivar, instead of the DD of subgroups of cultivars as is currently done in the PlanejArroz software (Steinmetz et al., 2021b), to estimate the date of occurrence of the main PDS, for cultural management purposes.

## Conclusions

The vegetative period (from the emergence-E to the panicle differentiation-R1) is the one with the highest accumulated degree-days, around 48% of the entire cycle, and also the greatest differences between cultivars when compared to the reproductive period 1 (from R1 to anthesis-R4) and reproductive period 2 (from R4 to full maturity of the panicle grains-R9);

The subperiod with the highest accumulated degree--days is between the four-leaf and the panicle differentiation stages (V4-R1), beeing also the one with the largest differences between cultivars.

## Authors´ contribution

S. STEINMETZ was responsible for the design of the work, acquisition and analysis of data and in writing the article. A. M. MAGALHÃES JÚNIOR, A M. and P. R. R. FAGUNDES helped in defining the cultivars to be evaluated in each season and in writing the article. S.V. CUADRA and I. R. de ALMEIDA collaborated in writing the article.

## Acknowledgements

The authors would like to thank the trainees at Embrapa Clima Temperado who helped in obtaining the phenological data over the years: Alexandre N. Deibler; Anderson B. Schneider; André da R. Ulguim; Eduardo Goulart; Felipe L. de L. Nobre; Igor N. Schneid; Jackson B. A. Pintanel; Jonathan G. Oliveira; Rafael C. Santos; Shemene J. S. A. Audeh; Silas S. Costa; the Assistant Denise D. Dos Santos for her help in tabulating the data; and to Researcher Ricardo A. Valgas for the statistical analysis of the data.

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CITATION

STEINMETZ, S.; MAGALHÃES JÚNIOR, A.M.; FAGUNDES, P.R.R.; CUADRA, S.V.; ALMEIDA, I.R. Accumulated degree-days to reach the main plant developmental stages of irrigated rice cultivars. **Agrometeoros**, Passo Fundo, v.30, e027129, 2022.

agrometeoros
REVISTA DA SOCIEDADE BRASILEIRA DE AGROMETEOROLOGIA

ISSN 2526-7043 www.sbagro.org.br DOI: http://dx.doi.org/10.31062/agrom.v30.e027129

# Acúmulo de graus-dia para atingir os principais estádios de desenvolvimento da planta em cultivares de arroz irrigado

**Silvio Steinmetz[1(*)], Ariano Martins de Magalhães Júnior[1], Paulo Ricardo Reis Fagundes[1], Santiago Vianna Cuadra[2] e Ivan Rodrigues de Almeida[2]**

[1]Embrapa Clima Temperado. Rodovia BR 392, km 78, Caixa Postal 403, CEP 96.010-971 Pelotas, RS.
E-mails: silvio.steinmetz@embrapa.br, ariano.martins@embrapa.br e paulo.fagundes@embrapa.br
[2]Embrapa Agricultura Digital. Av. Dr. André Tosello, 209 – Cidade Universitária, CEP 13083-866 Campinas, SP.
E-mails: santiago.cuadra@embrapa.br e ivan.almeida@embrapa.br
[(*)]Autor para correspondência.

INFORMAÇÕES

**História do artigo:**
Recebido em 9 de setembro de 2022
Aceito em 29 de novembro de 2022

**Termos para indexação:**
*Oryza sativa* L.
tempo térmico
fenologia

RESUMO

O objetivo deste trabalho foi determinar o acúmulo de graus-dia para atingir seis estádios de desenvolvimento da planta (EDP) de cultivares de arroz irrigado. Experimentos de campo foram conduzidos na Estação Experimental Terras Baixas (ETB) da Embrapa Clima Temperado, município de Capão do Leão, RS, durante 12 safras, sendo utilizadas seis épocas de semeadura em cada safra. Dez plantas de cada cultivar foram marcadas e tiveram os EDP acompanhados durante todo o ciclo. O acúmulo de GD (°C dia) foi calculado por meio do somatório da diferença entre a temperatura média diária do ar (Tm) e a temperatura base (Tb=11°C), da emergência até a data de cada estádio. Os resultados indicaram que os GD para atingir a antese (R4) representaram, na média, cerca de 77% do ciclo total (R9), variando de 73% para a IRGA 421 a 91% para a Epagri 109. O período vegetativo (da emergência-E ao R1) é o que apresenta o maior valor médio de GD, em torno de 48% do ciclo total, e também as maiores diferenças entre as cultivares quando comparado ao período reprodutivo 1 (R1-R4) e ao período reprodutivo 2 (R4-R9).



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