Phenological stages of Proso millet (Panicum miliaceum L.) encoded in BBCH scale

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Abstract

As a result of climate change, causing high temperature, erratic precipitation and extreme meteorological events, in recent times in Italy productivity of Maize is becoming less reliable. Climate change effects are accompanied by the increase in the presence of mycotoxins and various pathogens, which contribute to the reduction of the possibility of successfully producing Maize. In this framework, Proso Millet (*Panicum miliaceum* L.) may be an interesting alternative, as it is a relatively low-demanding crop, highly drought-resistant, and can be employed, similarly to Sorghum, in rotation, maintaining a certain amount of biodiversity and contributing to the revenue for the farmers. Moreover, Proso Millet has a very short cycle, and may be used as a catch crop, when other crops have failed or after their harvest. Millet used to be cultivated in ancient times in Italy, but then it was abandoned in favor of Maize, so now it is necessary to re-define proper agricultural practices and managements, as well as to remedy to the lack of an exact description of its phenological development. In the frame of a Life-CCA EU project, called Growing REsilience AgriculTure – Life (GREAT LIFE), aim of this work is to encode phenology of Proso Millet using BBCH scale. The lack of an exact definition of Proso Millet phenology is a major drawback in progressing in research on this crop, which could be a very valuable tool for improving the resilience of agro-ecosystems to climate change in the Mediterranean basin. For this purpose, Proso Millet was cultivated in two experimental sites in the Emilia-Romagna region (North of Italy). The crop was closely monitored throughout the life cycle, in order to document, even photographically, the achievement of the subsequent phenological phases (including the time necessary to reach each phenological stage, expressed as Days After Sowing - DAS). Thanks to weather data collection from agrometeorological stations close to the experimental fields, it was possible to correlate the phenological development to temperature-driven heat-unit accumulation (Cumulated Growing Degree Days -CGDD), using the single triangle method (useful tool for forecasting purposes). Ancillary agronomic data have also been collected, for completeness. This study well describes primary and secondary phenological stages of Proso Millet, managing at encoding them in the BBCH scale and contextually providing DAS and CGDD values necessary to achieve the different phenophases. The difference observed between the two experimental sites in reaching each BBCH stage according to both CGDD and DAS is mostly restrained, suggesting that this work may represent a valid first tool in defining the phenological development of Proso Millet in the areas of Northern Italy. The effort made to encode Proso Millet phenology in BBCH scale may be useful to give to researchers comprehensive indications for future agronomic surveys on the crop. The agronomic data collected show that the crop had a good agronomic performance despite the adverse weather pattern during the season, enlightening for farmers the opportunity offered by Millet in Italy as a resilient crop.

Keywords

Proso Millet, Phenology, Resilient Crops, Climate Change, Adaptation.

1. Introduction

Proso Millet (*Panicum miliaceum* L.) is a small seeded cereal of the Gramineae family. All over the world, about 20 different species of cropped Millet exist, which together make Millet the sixth most important cultivated cereal, representing a staple food for one third of the world population as a major source of energy and protein, especially in Asian and African countries (Habiyaremye et al., 2017). Other than food, Millets are cropped also for forage, feed and fuel (Habiyaremye et al., 2017). Proso Millet requires very little water if compared with other cereals, and converts water most efficiently to dry matter/grain (Theisen et al., 1978; Hulse et al., 1980). In fact, *P. miliaceum* L. can grow as a non-irrigated crop in arid lands with as little as 200–500 mm of average annual precipitation (Ceccarelli and Grando, 1996), and as a C4 species it can efficiently fix carbon under adverse conditions such as drought, high temperatures and limited CO_2 and nitrogen, thanks to its low transpiration ratio (Habiyaremye et al., 2017). Proso Millet also avoids drought by rapidly reaching maturity (Baltensperger et al., 1995). Specifically, depending on the variety, the crop cycle length spans from 60 to 90 days, and it can be grown as a full season or as secondary crop with winter cereals (Shayegan et al., 2008). All these features, combined with the fact that Millet has high nutritive value as a source of energy, good quality protein and micronutrients (Hulse et al., 1980; Pathak, 2013; Habiyaremye et al., 2017), make it an interesting crop for adaptation to climate change in the Mediterranean basin, characterized by high temperature, heat waves, erratic precipitation, extreme meteorological events (both floods and droughts). Proso Millet is the Millet species commonly cultivated in the North of Italy from the Bronze age (Tafuri et al., 2009). Although in the recent past it has lost much of its importance (becoming in fact a minor crop) in favor of Corn, nowadays productivity of Maize is becoming less reliable, as a consequence of climate change effects accompanied by the increase of mycotoxins and various corn pathogens. In this framework, Proso Millet may be an interesting alternative to Maize and can be employed, similarly to Sorghum, in rotation to increase the resilience of agro-ecosystems, maintaining a certain amount of biodiversity.

Some information on Proso Millet different stages of growth can be found in research papers but there is none that specifically describes its phenological development encoded in the BBCH scale (Meier, 1997). This paper is aimed to fill this gap. Growth and development characteristics of *Panicum miliaceum* L. were explained in detail by Cardenas et al. (1983). They distinguished three phases: vegetative, reproductive, and ripening, which are further sub-divided into distinct stages. The vegetative phase covers the period from germination to panicle initiation; depending on the cultivar used and on the climate in the area, may be completed in 16 to 20 days after sowing. An increase in number of leaves, tiller buds, and plant height are characteristics of this phase. The period (20 to 25 days) from panicle differentiation to flowering of the main culm is the reproductive phase. This phase starts when the panicle primordium is longer than 0.5 mm. Rapid elongation of stem internodes and an increase in leaf area accompanied by more tillers are noticed in this phase. The ripening phase starts at flowering or blooming and continues to the end of physiological maturity, which covers a period of 20 to 30 days. Throughout this period, the plant actively accumulates dry matter, particularly in grains. Rodriquez et al. (1990) studied the dry matter accumulation pattern of two cultivars of Proso Millet with optimum nutrient and water availability. From anthesis to maturity, dry matter accumulated at a rate of 0.5 mg ha^{-1} day^{-1}. Panicles at maturity accounted for 55% of the total plant dry matter, which is a high value if compared to Wheat and grain Sorghum. The authors concluded that since Proso Millet accumulates higher dry matter in the reproductive parts compared to Wheat, Maize, and Sorghum, it may be advantageous to grow Proso in dry conditions and in short growing seasons. Proso Millet is characterized by a staggered ripening, meaning that seed maturity proceeds from the top to the bottom of the panicle. For this reason, delay in harvesting may cause yield losses due to shattering (Theisen et al. 1978; Baltensperger et al., 1995). At maturity, grains generally present about 20% or less moisture. A clear and internationally recognized way to describe phenological development of plants uses the BBCH (Biologische Bundesanstalt, Bundessortenamt and CHemical industry) encoding. The BBCH scale presents the growing stages of plants using a double digit code going from 00 to 99. BBCH growth stages represent a detailed study of the plant and the plant's growth from germination to harvest, allowing a uniform coding of similar growth stages of very different plant species. This work of Proso Millet exact phenology definition is in the frame of a Life-CCA EU project, called Growing REsilience AgriculTure – Life (GREAT LIFE). GREAT LIFE general objective is to implement an innovative and integrated approach, from crops to market test, in order to face the effect of climate change on the agricultural activities not only in Italy but in the entire Mediterranean basin. Both at a national and European level, GREAT LIFE intends to show how - through crops substitution and through the promotion of resilient food among consumers - it is possible to effectively address EU adaptation priorities in the field of agriculture and rural development. GREAT LIFE focuses on a selection of strategic objectives, and in particular: the biodiversity improvement, by promoting field activities based on two species, Proso Millet and Sorghum, cropped in Italy since 3500 BC (consequently both considered autochthonous), the introduction of conservative agricultural practices among farmers, the improvement of the overall sustainability of the agro-ecosystem, especially reducing water consumption, through the cultivation of resilient crops and the adoption of rational rotation schemes and sustainable agronomic practices. The lack of an exact definition of Proso Millet phenology is a major drawback in progressing in research on this crop; for this reason, this is an important part of the project. Moreover, the temperature at which the crop grows has a great influence on how it develops. For this reason, the calculation of temperature-driven heat-unit accumulation (CGDD) is important, and knowing the relationship between CGDD and phenological BBCH stages can help to successfully cultivate Proso Millet. In the framework of the GREAT LIFE project (LIFE17 CCA/IT/000067), Proso Millet was cultivated in four areas in the Emilia-Romagna region, two of them were used for phenological data gathering.

2. Materials and Methods

2.1 Experimental sites

Proso Millet cultivar used in this trial is "Miglio Biondo" (from Arcoiris company, variety code B109-SFU), produced in Italy. Two sites in the Emilia-Romagna region were used for phenological data gathering in 2019 agronomic season. The first site is in the DISTAL Agricultural Garden (AG), inside the Department Campus in Bologna (Lat 44°30'54'' Long 11°24'21''). Here plots have the size of 2 x 2 m^2, and Millet was introduced into the normal Agricultural Garden cultivation scheme. The second site is in Azienda Villa Masini (VM, Ravenna, Lat 44° 15’ 59’’, Long 12° 07’ 48’’), with experimental plots of the dimension of 5,5 x 41 m^2 for each summer crop tested during the experiment (Millet, Sorghum, Maize). Moreover, in VM site Millet and Sorghum were cultivated in open fields, for grain production, with a size of 10800 m^2 (54 m x 200 m) for each crop.

2.2 Experimental details

Millet sowing is recommended from the end of spring to the beginning of summer (at least 12 °C in the ground, as reported in Baltensperger, 1996), usually sowing with a grain seeder at a distance of 10-14 cm between rows (150-250 plants per square meter) and a depth of 1-2 cm if the soil is moist, a little deeper if it is dry. Sowing rate is 30/35 kg ha^{-1} (40/50 kg ha^{-1} in poor soils).

In AG site (planting date 18/04/2019) sowing was carried out manually, whereas in VM site (planting date 17/04/2019) was performed with a grain seed drill after 2 false seedbed carried out with a tiller. Experimental details are presented in Table 1.

Table 1: Experimental details for DISTAL Agronomy Garden (AG) and Villa Masini (VM).

	AG	VM
Soil management	Use of cultivator at the end of previous season	2 False seed bed before sowing
Planting date	18/04/2019	17/04/2019
Sowing depth	2 cm	2 cm
Inter-row	8 cm	8 cm
Seed density	4 g/m^2	4 g/m^2

2.3 Weather data

Both experimental sites are in the Emilia-Romagna region, in the North of Italy, with a sub-humid climate, an average regional annual air temperature of about 12.8°C and mean regional annual precipitation amount of about 924 mm (Antolini et al., 2017). In order to have an idea of the climate of the sites, a Bagnouls and Gaussen plot of both areas is shown in Fig. 1. In this case, data for AG comes from the main agrometeorological DISTAL station, that is in Cadriano (Lat 44° 33' 03'', Lon 11° 24' 36'', 6 km far from AG, Matzneller et al., 2010) and from ERA5 reanalysis data (Copernicus Climate Change Service C3S, 2017) for the grid point of San Pietro in Vincoli (approximately 7 km from the experimental fields) (Ben Hamouda et al., 2019) for VM. The choice to use reanalysis data comes from the easy availability of this dataset, that spans from 1961 to 2018, while the measured dataset in the same site is much shorter and with some missing data.

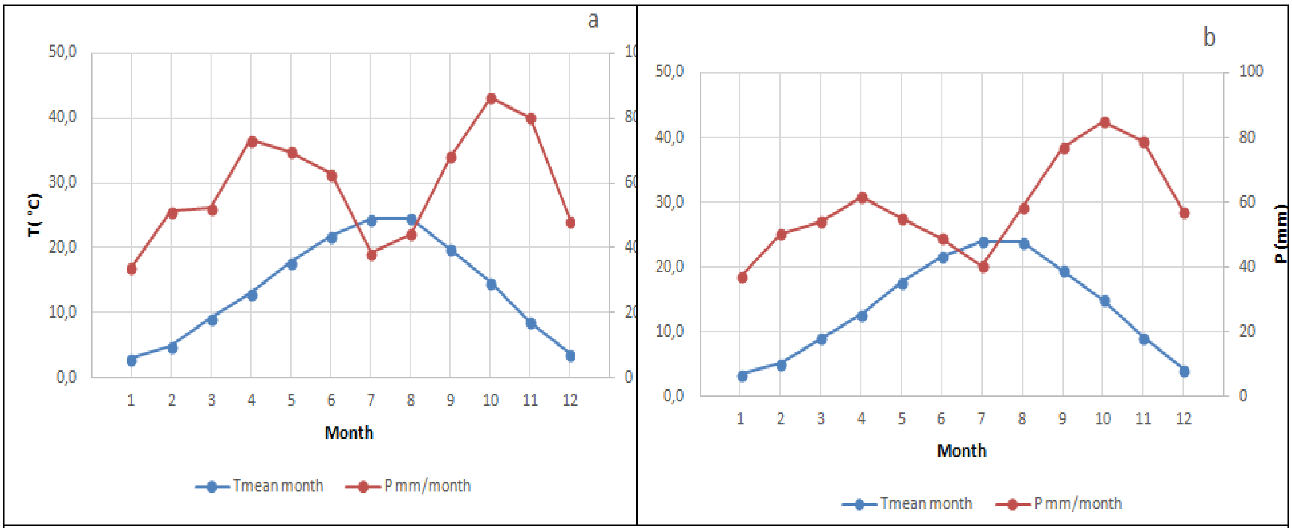


Figure 1: Climatic diagram (Bagnouls and Gaussen graph) For the two experimental areas: a) Cadriano (BO); b) San Pietro in Vincoli (FC), based on a 30 years averaged data 1988-2017.

Agrometeorological data (maximum, minimum, average daily air temperature and daily precipitation) were downloaded from the DISTAL agrometeorological station for AG site, and from the ARPAE-Simc agrometeorological station sited in San Pietro in Vincoli for VM site. Maximum and minimum air temperature values were used to calculate CGDD from sowing date using a temperature threshold of 10°C as in Anderson (1994). The CGDD were calculated using the single triangle method (Zalom et al. 1983, Snyder et al., 1999). This technique uses daily maximum and minimum air temperature values to produce a triangle to approximate temperature variation during the day, then calculates the CGDD value by determining the area above the threshold and below the triangle. The use of maximum and minimum air temperatures for calculating CGDD with this method gives good accuracy and the error level is acceptable in comparison with the use of hourly air temperature values (Pellizzaro et al. 1996; Zalom et al. 1983). CGDD in both sites are compared, as references, with historical CGDD, calculated using a measured dataset from the agrometeorological station of Cadriano for AG site and reanalysis data from ERA5 for the grid point of San Pietro in Vincoli for VM. Weather conditions for 2019 crop cycle are shown in Fig 2, and compared to the 30 years average air temperature (1988-2017).

2.4 Phenological Data collection

The sowing date has just a 1-day difference between the two sites, as indicated in Table 1, and the growing plants were closely observed and photographed, several time per week in AG site, weekly in VM site. In order to closely monitor the phases between sowing and emergence (BBCH stage 00 to BBCH stage 10), a germination lab test was performed: 6 seeds were surface sterilized with 10% sodium hypochlorite for 7 minutes, and then rinsed 5 times with deionized water. The sterilized seeds have been placed in 2 Petri dishes (3 seeds per dish) on filter paper soaked with deionized water, and then put in growth chamber with photoperiod 16 hours dark (20°C) / 8 hours light (30°C).

2.5 Additional data

A series of additional **agronomic** data are here presented for completeness. In AG site weeding was carried out manually, whereas in VM site no weeding operations were performed after sowing, in order to investigate as an ancillary data the crop ability to cover the soil and compete with weeds. Table 2 shows crop management data. With regard to harvest, in AG site harvesting has been performed when BBCH stage 93 (grains-loosening) had already started, in order to assess the impact of grain loss on yield. In VM site harvesting was performed at BBCH stage 91 (Over-ripe). On harvest day, 1 m^2 for AG site and 3 separated sampling areas of 1 m^2 for VM site have been evaluated for the following parameters: lodging (%), ground coverage (%), weeds presence on the monitored surface (%), diseases incidence and severity (in a 0-10 scale, with 0 = absence of diseases and 10 = compromised plants), yield per panicle (measured on 5 panicles), plant height (measured on 5 plants at the panicle insertion), panicle length (measured on 5 panicles), grain color. Results are reported in Table 8.

Table 2: Additional agronomic characteristics for DISTAL Agronomy Garden (AG) and Villa Masini (VM).

	AG	VM

Fertilization	none	none
Irrigation	none	none
Weeding method	manual	none
Weeding date	Every 10 days	none
Harvest date	07/08/2019	01/08/2019

For completeness, the principal physico-chemical soil properties, macronutrients and micronutrients content were previously characterized in VM site, according to the official analysis methods and techniques (GU 248/99; UNI EN 13657:2004; UNI EN ISO 11885). Table 3 reports VM site soil characteristics.

Table 3: Soil characteristics in Villa Masini site
(E.C. – Electric conductibility; $CaCO_3$ – Total carbonates; TOC – Total organic carbon; TN - Total Nitrogen)

Soil physico-chemical properties										
pH (H_2O)	**E.C.**	**$CaCO_3$**	**Skeleton (Ø >2 mm)**	**Texture**				**Soil organic matter**	**TOC**	**TN**
				Sand (Ø 2000-50 µm)	**Silt (Ø 50-2 µm)**	**Clay (Ø <2 µm)**	**USDA class**			
1:2,5	**µS cm^{-1}**	**g kg^{-1}**	**%**	**g kg^{-1}**				**%**	**g kg^{-1}**	
8.16	92.5	178.0	7.8	221	625	154	Silt-loam *	2.69	15.6	0.98

Total Macronutrients (g kg^{-1})													
Al	B	Ba	Ca	Fe	K	Mg	Mn	Na	P	S	Si	Sr	Ti
32.8	0.38	1.74	63.9	22.1	9.04	12.4	0.75	1.09	0.79	0.27	0.18	0.25	0.71

Total Micronutrients (mg kg^{-1})													
As	Be	Cd	Co	Cr	Cu	Li	Mo	Ni	Pb	Sb	Sn	V	Zn
6.38	1.11	0.232	12.7	73.2	57.6	47.7	0.32	45.1	25.7	1.35	2.11	62.6	77.4

3. Results

3.1 Meteorological data

The climate of the two experimental sites is not very different, as it is possible to see comparing the two graphs of Figure 1. The mean annual precipitation amount is 709 mm in AG and 703 in VM, with very similar B&G diagrams. The AG area is slightly warmer than VM. Figure 2 shows the meteorological conditions for 2019 crop cycle in both sites, with mean air temperature compared with the climatological average. Both in AG and VM there was a quite cold and rainy May, followed by heat waves in June and July. The total precipitation during the crop cycle was 247.4 mm and 270.8 mm respectively. The rainfall event on the 22th of June in AG is a hailstorm that caused some damage to the plot, and added 34.2 mm to the total rainfall amount.

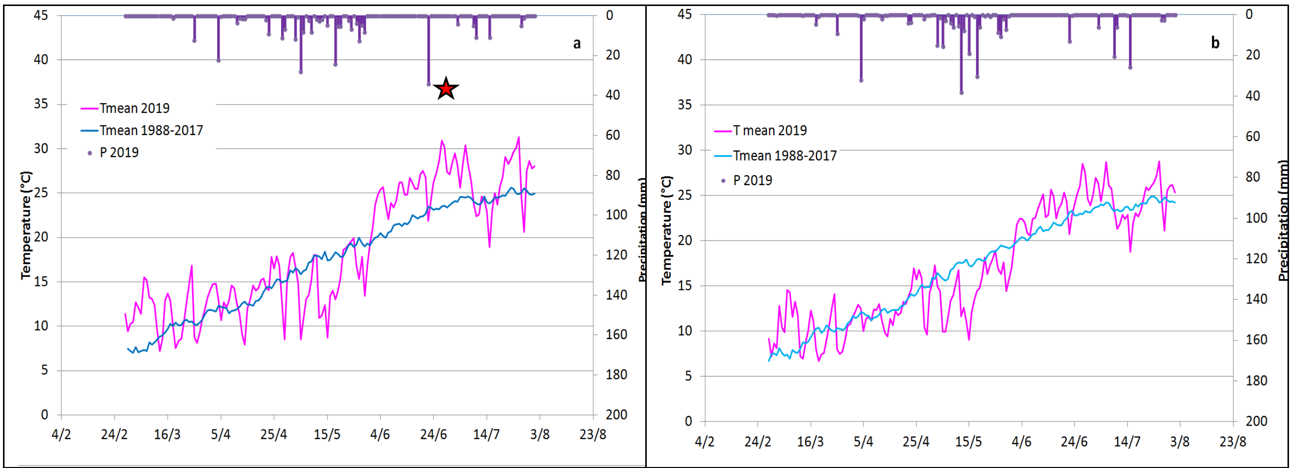


Figure 2: Meteorological data for the two experimental areas: a) DISTAL AG (BO); b) San Pietro in Vincoli VM (FC). As a reference, a line representing the 30 years mean air Temperature is added. The star shows the hailstorm that caused some damage to the plot (22th of June)

3.2 Plant phenology

Experimental grown Proso Millet plants were closely examined and the observations recorded are presented in Table 4 and 5. Specifically, Table 4 presents phenological data for AG site; differences between the two sites are small and they will be presented later. The table reports the date, the days after sowing, the cumulative degree days for each survey and the description of the main and secondary stages. For most of them, photos are also available and their number is reported in the table. Table 5 reports the phenological stage of seeds (from 00 to 10), daily checked in the growth chamber. All the photos taken in both AG and VM sites and representing main phenological stages, as specified in Table 4, are listed in Table 6. The pictures aim to help recognizing the plant stages in the field. Moreover, Figure 3 shows a qualitative representation of Proso Millet life cycle.

Assessing plant phenological stage by calculating CGDD allows also to forecast stages, but it is necessary to know thermal amount typical of the plant to reach each stage. Figure 4 shows Cumulated Growing degree days for Proso Millet during the crop cycle 2019, in the experimental sites of AG (a) and VM (b), showing as a reference the line representing CGDD calculated from the 30 years mean air Temperature. Both graphs show some differences between the actual and the climatological phenological progress. The arrows show the end of flowering and hard dough ripening phase occurrence.

Table 4: description of main and secondary stages of Proso Millet development in AG. Together with the date, the Days after Sowing (DAS) are indicated, with BBCH stage and Cumulated Growing Degree Days (CGDD), considering a threshold of 10°C (Anderson, 1994).

Date	DAS	Main growth stage	Stage code (BBCH)	Stage description	CGDD
18 April 2019	0		00	Dry seed (**photo 1**)	
			01	Beginning of seed imbibition	
			03	Seed imbibition complete	
		Stage 0 Germination	05	Radicle emerged from caryopsis	
			06	Radicle elongated **(photo 2)**	
			07	Coleoptile emerged from caryopsis **(photo 3)**	
			09	Emergence: coleoptile penetrates soil surface	
			10	First leaf through coleoptile **(photo 4)**	
29 April 2019	11		11	First leaf unfolded **(photo 5)**	65.7
3 May 2019	15	Stage 1 Leaf development	12	2 leaves unfolded **(photo 6)**	93.6

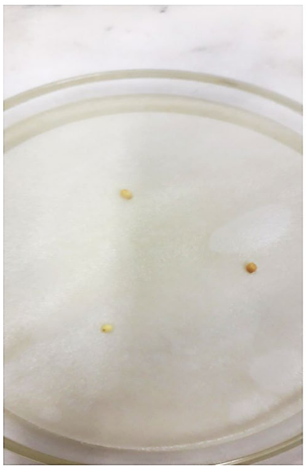
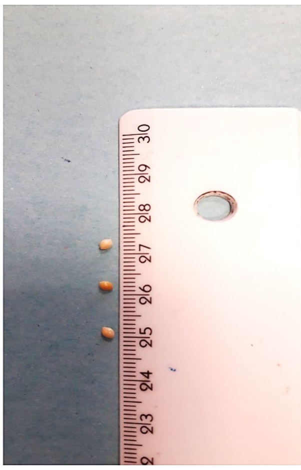
			...		
7 June 2019	50		16	6 leaves unfolded **(photo 7)**	338.9
10 June 2019		Stage 2 Tillering	20	No tillers detectable	
10 June 2019	53		21	Beginning of tillering : First tiller detectable **(photo 8)**	380.3
10 June 2019		Stage 3 Stem elongation	30	Beginning of stem elongation	
10 June 2019	53		31	First node detectable, at least 1 cm above the bud **(photo 9)**	380.3
14 June 2019	57		32	second node detectable, at least 2 cm above first node	438.7
		Stage 4 Booting	41	Early boot stage: flag leaf sheath extending	
			45	Late boot stage: flag leaf sheath swollen	
			49	The first visible awn	
14 June 2019	57	Stage 5 Heading	51	Panicle comes out the tip of the sheath **(photo 10)**	438.7
17 June 2019	60		59	End of heading: panicle fully emerged **(photo 11)**	485
17 June 2019	60	Stage 6 Flowering	61	Beginning of flowering: first anthers visible	485
			65	Full flowering: 50% of anthers mature	
17 June 2019	60	Stem elongation continues	33	The third node is at least 2 cm above the second node **(photo 12)**	
21 June 2019	64	Stage 6 Flowering	69	End of flowering: all spikelets have completed flowering **(photo 13)**	549.2
1 July 2017	74	Stage 7 Fruit development	75	Milky ripe: grain content milky, grains reached final size and are still green **(photo 14)**	720.3
11 July 2019	84	Stage 8 Ripening	85	Soft dough: grain content soft but dry. Fingernail impression not held	896
15 July 2019	88		87	Hard dough: grain content solid. Fingernail impression held **(photo 15)**	949.8
	99		89	Fully ripe: grain hard, difficult to divide with thumbnail	

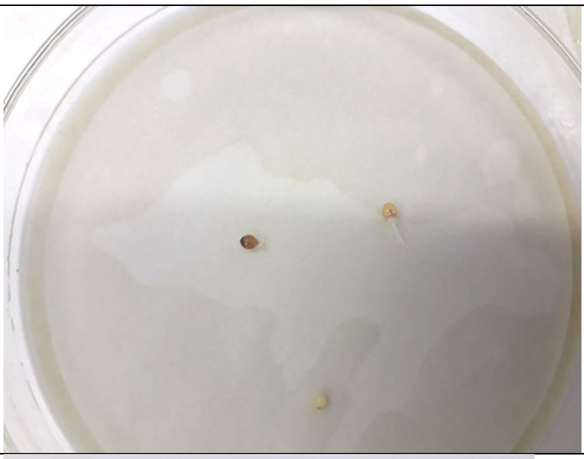
				(photo 16)	
26 July 2019			91	Over-ripe: grain very hard, cannot be dented by thumbnail **(photo 17)**	1135.3
30 July 2019	103	Stage 9 Senescence	93	Grains loosening in day-time **(photo 18)**	1196.4
			97	Plant dead and collapsing	
7 August 2019	111		99	Harvested product	1328.2

Table 5: pre-emergence phenological stages of seeds grown in a Petri dish in a growing chamber, checked daily.

Day	**BBCH Phenological stage**
Day 1	00
Day 2	03
Day 3	05
Day 4	07
Day 5	Coleoptile elongation
Day 8	10
Day 11	11

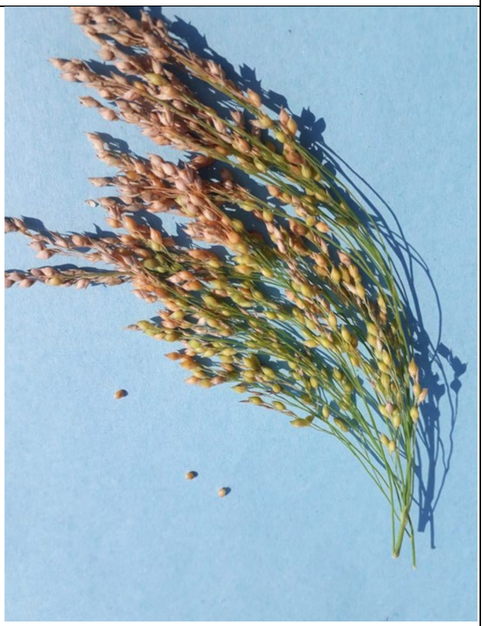
Table 6: Photos of principal phenological stages, taken in both experimental sites (P = Photo number, B. S. = BBCH stage)

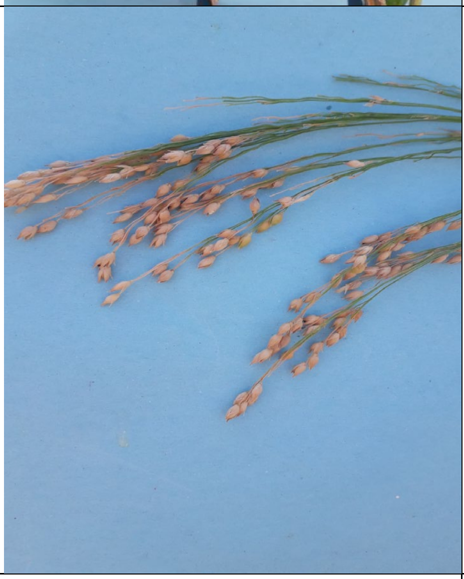
P	**B. S.**	**Photo**	
1	**00**	 	

2	**06**		
3	**07**		
4	**10**		

5	**11**	 			
6	**12**		**7**	**16**	

8	**21**		**9**	**31**	
10	**51**		**11**	**59**	

12	**33**		**13**	**69**	
14	**75**		**15**	**87**	

16	**89**		**17**	**91**	
18	**93**				

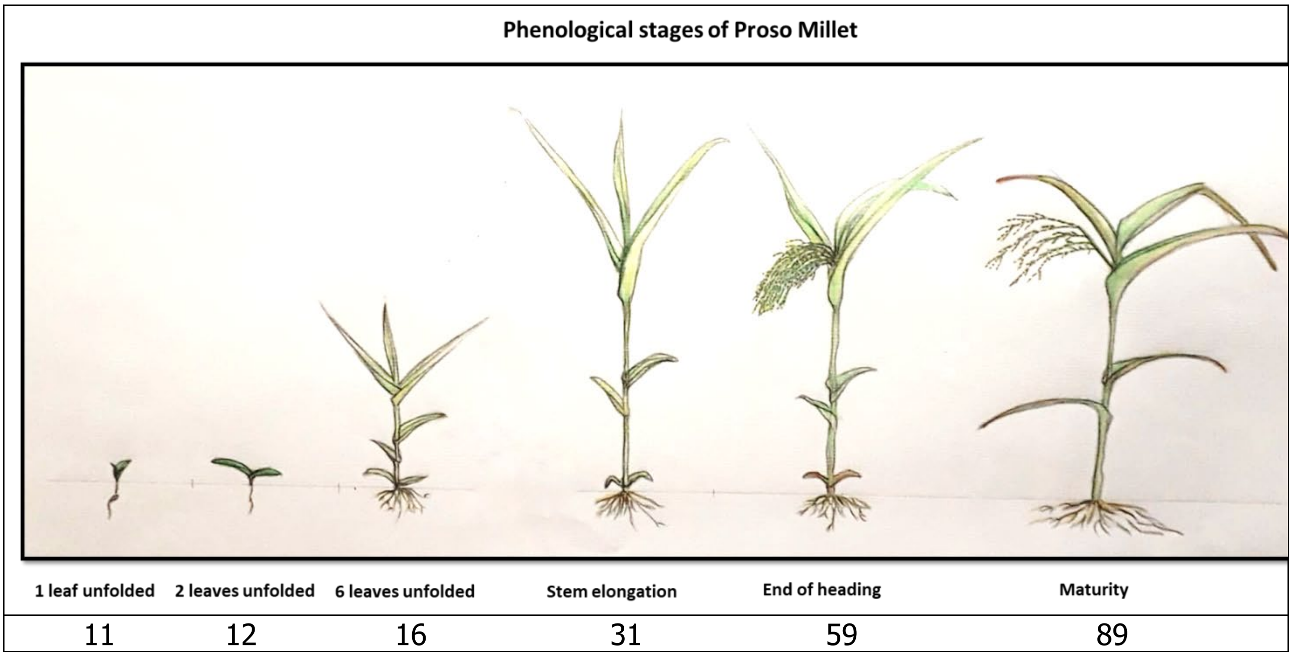


Figure 3: Qualitative representation of Proso Millet life cycle and corresponding BBCH stages (handmade drawing by Giulia Feduzi)

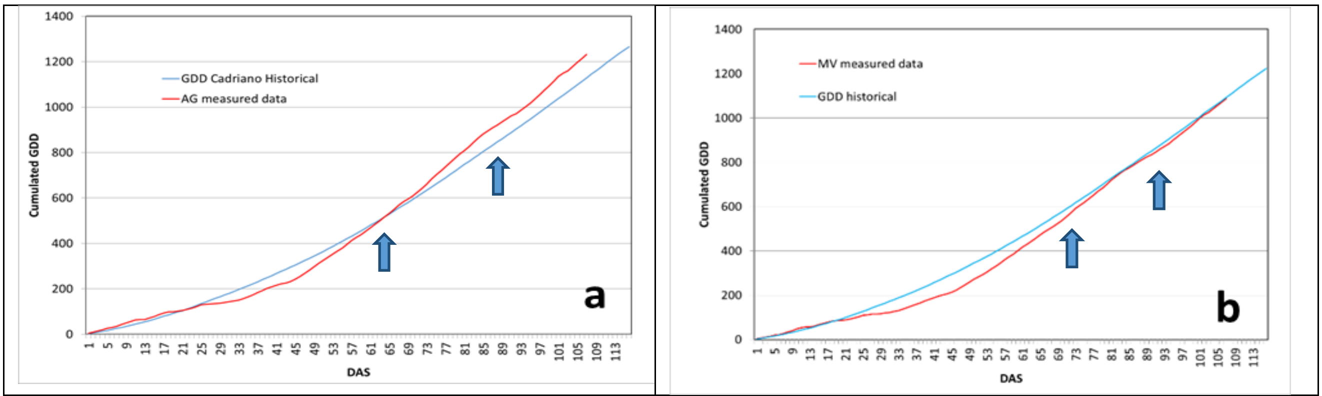


Figure 4: Growing degree days for Proso Millet during the crop cycle 2019, in the experimental sites of AG (a) and VM (b). As a reference a line representing GDD calculated summing the 30 years mean air Temperature is added. The arrows show the end of flowering and hard dough ripening phase occurrence**.**

Phenological stages appearances for both sites are plotted in Figure 5. It presents the comparison between the two experimental sites of BBCH stages expressed as a function of CGDD (a) and according to DAS (b). Table 7 reports data shown in Figure 5 (a and b).

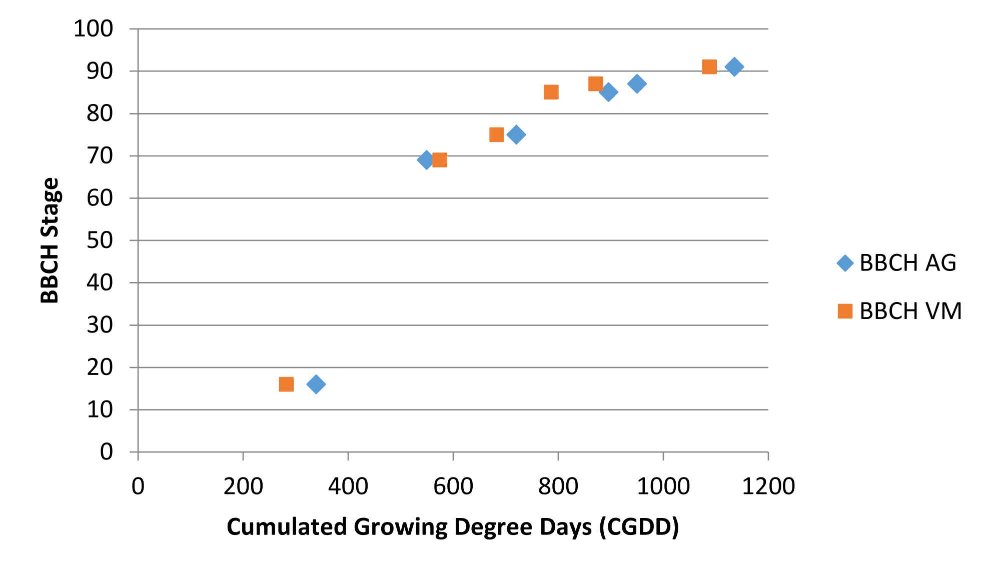


Figure 5a: Comparison between the two experimental sites of BBCH stages according to CGDD

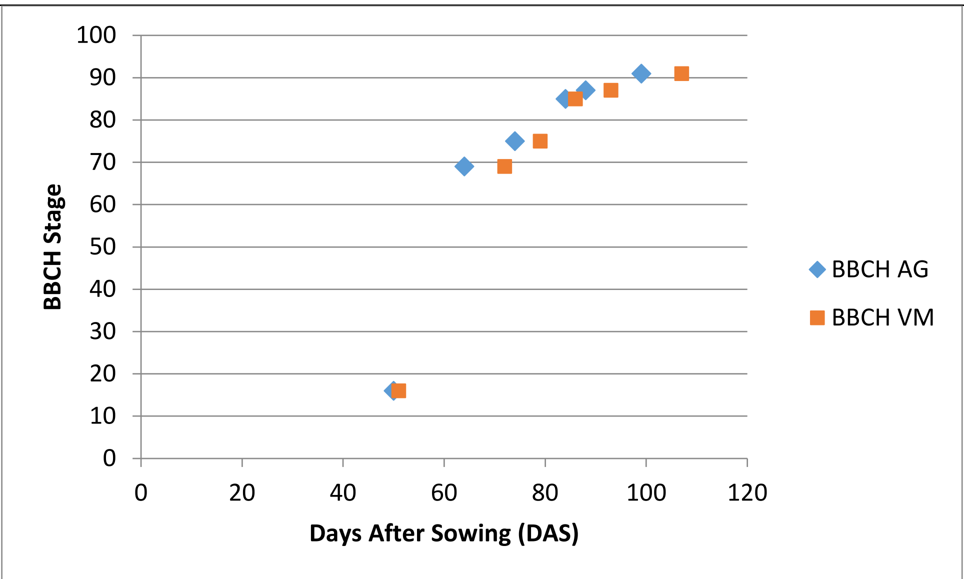


Figure 5b: Comparison between the two experimental sites of BBCH stages according to DAS

Table 7: data shown in Figure 5a and 5b

CGDD	BBCH AG	BBCH VM	DAS	BBCH AG	BBCH VM
282		16	50	16	
339	16		51		16
549	69		64	69	
574		69	72		69
683		75	74	75	
720	75		79		75
787		85	84	85	
871		87	86		85
896	85		88	87	
950	87		93		87
1088		91	99	91	
1135	91		107		91

The difference observed between the two experimental sites in reaching each BBCH stage according to CGDD is mostly restrained (lower than 60 GDD in most cases, except BBCH stage 85 and 87, that present a span of 109 and 79 GDD between the two sites, respectively). The difference observed between the two experimental sites in reaching each BBCH stage according to DAS is very low (always lower than one week except BBCH stage 91, that presents a time span of 8 days between the two sites). As said in literature, panicles show quite a staggered ripening. Figure 6 shows the progressive staggered ripening of a panicle from A to D. Specifically, as distal grains of the panicle reached soft dough maturity, a color change from green to yellow of their glume (and a contemporary beginning of senescence of basal leaves) has been observed. Maturity proceeds until grains start shattering. For accuracy, ripening started from the top of the panicle and gradually continued to its bottom. As the bottom part of the panicle reached full-ripening, the distal part of it started grain loosening.

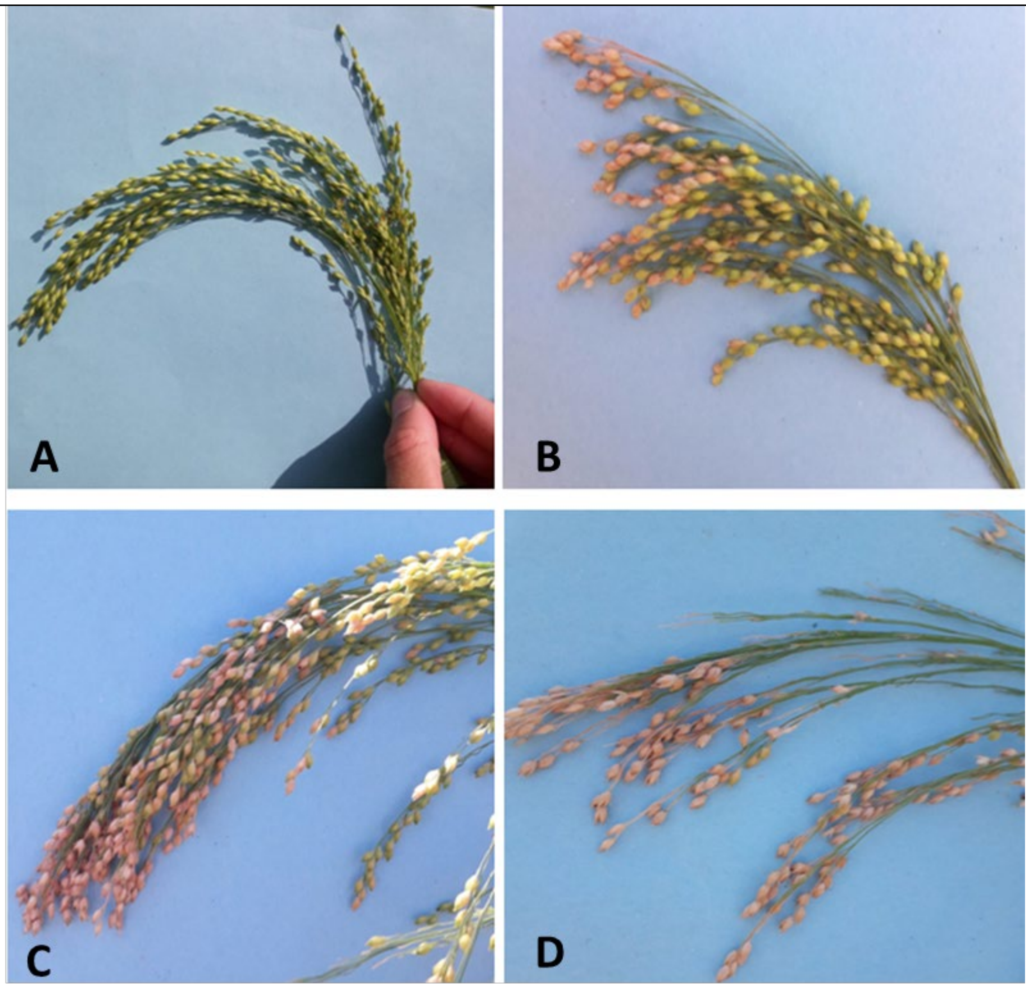


Figure 6: staggered ripening of panicle. From photo A to D is included a time span of 15 days.

3.3 Crop cultivation

Table 8 reports the results of agronomic parameters measured on harvest day. In VM site the crop competitiveness with weeds was quite good, especially after stem elongation, both in experimental plots and in open field condition, as shown in Figure 7, and as indicated by ground coverage (%) and weeds presence (%), reported in Table 8. With regard to harvest, the product has been harvested in two different phenological phases in the two experimental sites, as already said. Globally, Proso Millet in VM site had a yield of 2.2 t/ha. Yield per panicle has been approximately 42% lower in AG site compared to VM site, showing a considerable yield loss caused by grain shattering, occurred in BBCH stage 93. Plant height and panicle length could have been lower in AG site as a consequence of the hailstorm occured on 06/22/2019

Figure 7: crop competitiveness with weeds in open field in VM site (milky ripe stage)

Table 8: Results of agronomic parameters evaluated on harvest day

Parameter	**AG site**	**VM site (1st m²)**	**VM site (2nd m²)**	**VM site (3rd m²)**
Phenological stage (BBCH)	93	91	91	91
Lodging %	0	0	0	0
Ground cover %	50	95	100	85
Weeds presence %	0	5	10	20
Diseases I. and S.	0/10	1/10	0/10	0/10
Yield/panicle (g) (mean of 5 values)	1.27±0.4	3.76±0.8	2.81±1.7	2.76±0.7
Plant height (cm) (mean of 5 values)	61.0±8.2	81.4±3.0	78.6±5.3	86.6±7.7
Panicle length (cm) (mean of 5 values)	19.0±4.2	31.0±5.6	32.8±5.2	35.2±8.8
Grain color	Yellow	Yellow	Yellow	Yellow

4. Discussion

Our investigation provides indications about the calculation of the CGDD necessary to reach the various phenological stages, useful for forecasting purposes. A previous work by Anderson (1994) tells us that two main stages, stem elongation (30) and flowering (61) are reached with 600 and 1100 CGDD respectively. Anderson calculated the thermal amount to reach each phenological stage using "Cope" Proso Millet in Akron, Colorado, where during his experimentation, from 1988 to 1990, growing season average precipitation and temperature were respectively 183 mm and 21.3 °C. Table 4 tells us that there is not full correspondence with these thresholds, and this may be due to the meteorological year as well as the agronomical management of plants, the different site of experimentation and Proso Millet cultivar used. In fact, phenology is commonly a plant trait characterized by a high plasticity, and it has always been difficult for researchers to explain the great variation observed in phenological responses, across time and space, as well reported in Wolkovich and Ettinger (2014). The only way to know more about this issue is to repeat the phenological observations for more than one year. Regarding the differences observed between the two experimental sites in reaching each BBCH stage according to DAS and CGDD it is important to notice that in AG site phenological stage was checked daily, although in VM site phenological stage was checked once a week (in this case 7 days is the experimental error of the observation). So we can assume that the difference observed can be at least partly explained by the different check time step. For this reason, it's conceivable that the phenological development according to DAS in AG and VM sites has been quite contemporary. In addition to providing new detailed information on the phenophases (main and secondary) of the species expressed in the BBCH scale, this study provides for the first time an indication of the thermal thresholds for Proso Millet phenological stages in Italy: for example, around 550 GDD for the end of flowering and about 1100 GDD for over-ripe.

Some interesting observation has been made in the experimental sites. Both in AG and VM sites, a low tillering level was observed. It is probable that the high sowing density has caused a low tillering rate, as reported in Enciclopedia Agraria Italiana (1972). Interestingly, tillering and beginning of stem elongation seemed to be simultaneous, and stem elongation continued even after heading phase. The massive hailstorm occurred in Bologna on June 22^{th}, 2019, caused the total lodging of the crop in AG site, but a good recovery has been observed in just 4 days (as shown in Fig 8). Anyway, it is possible that the lodging affected the vegetative growth of the crop and its productivity during the rest of the season. VM site yield of 2.2 t/ha can be considered a good result if compared with the average yield in Southern Europe in the last 10 years (1.8 t/ha - FAOSTAT), especially considering the organic management applied to the crop, without irrigation and fertilization. The yield value could be partially explained by the high seed density used (4g/m^2) and by the fact that we used Millet as principal crop in the agronomic season, whereas usually it is used as rotational crop within wheat-based production systems, or in marginal lands.

Figure 8: lodged crop after the hailstorm of 06/22/2019 (a) and recovery from lodging after 4 days (b) for the AG plot

5. Conclusions

This work represents an interesting case study for the assessment of phenological development of Proso Millet in Italy, with particular reference to chronological time and Cumulated Growing Degree Days required to reach the different stages, precious tools for forecasting purposes in the agronomic management, whose optimization is essential to enrich the resilience of agro-ecosystems to climate change in the Mediterranean basin. The effort made to encode Proso Millet phenology in the BBCH scale may be useful to give comprehensive indications for future agronomic surveys of the crop, allowing comparisons between very different plant species, and within the same species in different years and location. The study gives first useful indications about opportunity offered by this crop in Italy, and in particular in the Emilia-Romagna area as a catch and resilient crop, able to grow successfully in non-irrigated and non-fertilized conditions, with a rapid life cycle and good competitiveness with weeds in open field conditions. Overall, the crop showed a good agronomic performance despite the adverse weather pattern during the season, characterized by a cold and rainy May, followed by heat waves and hailstorms in June and July. The yield obtained was good, as compared with FAOSTAT data for southern Mediterranean area, even if cultivated with organic protocols.

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