http://dx.doi.org/10.22161/ijeab/2.3.3 ISSN: 2456-1878

Comparison of 4 Buckwheat Cultivars and 2 Planting Densities in 2 Mountain Places of Umbria (Central Italy)

Lisetta Ghiselli[1], Sigfrido Romagnoli[1], Remigio Tallarico[1], Luciano Concezzi[2], Stefano Benedettelli[1]

[1]University of Florence, Department of Agrifood Production and Environmental Sciences (DISPAA), Piazzale delle Cascine 18, 50144 Florence, Italy

[2]3A Agrifood Technology Park of Umbria (3A-PTA), Fraz. Pantalla, 06059 Todi, Italy

Abstract— *Buckwheat (Fagopyrum esculentum Moench) is a pseudocereal grown on limited extensions in Italy and Western Europe in general, but is currently the subject of considerable interest from the scientific community and consumers for its unique nutritional properties: it is rich in vitamins and mineral salts, dietary fiber and antioxidant substances, and it is free of gluten. This species also has agronomic characteristics that make it suitable for cultivation in mountain environments, enabling farmers to extend and change crop rotations: a short growing season, limited nutritional needs, good adaptation to acid soils, tolerance to pests and weeds. Buckwheat cultivation in Italy is more common in the Alps, but recently experiments have been carried out which have shown its good adaptation to the climatic conditions of the Apennines. In this paper, we present the results of an experimental field trial conducted in the year 2015 in two mountain localities of Umbria (Castelluccio di Norcia and Norcia) in which were compared 4 varieties and 2 seeding densities. The results confirmed the suitability of the mountain places of central Italy (especially those located at high altitudes) for the cultivation of buckwheat and indicated significant differences between yields and grain quality traits of different varieties. The different seeding rates resulted in significant differences in some biometric parameters of plants, but not in production yields.*

Keywords— Cultivar evaluation, Fagopyrum esculentum, Italy, organic farming, planting densities.

I. INTRODUCTION

Buckwheat (*Fagopyrum esculentum* Moench) is grown in mountain and marginal areas of many parts of the world [1]. Its cultivation in Italy dates back to the years around 1500 [2] and since then has spread in the Alps and to a lesser extent in the Apennines. Buckwheat has maintained a certain importance up to 1950-1960 in the cropping systems of these mountain areas, where the most commonly cultivated cereals (wheat, barley, corn) had limitations due to their climatic and soil requirements. In subsequent years, the availability of cereal cultivars more resistant to the climate of the mountain zones, but above all the progressive abandonment of the Italian mountains led to an almost total disappearance of this crop. The abandonment of the buckwheat cultivation, as well as representing a loss of biodiversity in those territories, brought into disuse various food specialties based on this pseudocereal, which is provided with important nutritional and health properties including a balanced amino acid composition of proteins [3], an abundant presence of dietary fiber including its soluble fraction [4], a considerable content of mineral macro- and microelements [4, 5] and rutin, a flavonoid with remarkable antioxidant properties [5, 6]. They are also present in buckwheat D-chiro-inositol and fagopyritols [7, 8], soluble carbohydrates with important effects on the human biochemistry including increased insulin sensitivity that causes a decrease in blood glucose in patients with diabetes mellitus [9, 10] and reduced symptoms in women with polycystic ovary syndrome, or PCOS [11]. Recently, some researchers have shown that a diet with buckwheat-enriched products can exert a protective effect on the development of cardiovascular disease by reducing circulating cardiovascular risk factors and markers of oxidative stress [12].

The disappearance of this crop from areas where the use of buckwheat was traditional in food preparation has led consumers to the use of foreign product (from Eastern Europe and Asia) where buckwheat is still equated to wheat as a strategic culture; however, foreign product does not offer the same guarantees of traceability and wholesomeness than that obtained in the European Union. Thanks mainly to the Rural Development Programs drawn up by the Italian regions and funded by the European Union, the spirit of which is to promote the revitalization of rural areas through the recovery of traditions and biodiversity, today numerous species disappeared or marginalized by the strength of industrial agriculture have been recovered. The Department of Agrifood Production and Environmental Sciences of the University of Florence started research on buckwheat since the years 1980-'90, aimed at the assessment of both indigenous germplasm and varieties of foreign origin, having as main objectives the following:

1) Promotion of an important crop to integrate human nutrition;
2) Recovery of biodiversity;
3) Enhancement of agriculture in mountain areas where monoculture or only grazing prevails;
4) Improvement of soil fertility;
5) Offer of a wider range of products from the mountain regions;
6) Development of a local supply chain of food products with health properties.

The trials we have undertaken to date were located in central Italy, whose territories along the Apennine mountains proved to be ideal for the growth of this species [13, 14]. Other researchers have also performed tests in the Apennine mountain areas with positive results [15, 16]. Based on our experience on this crop, in 2015 a comparison test was staged in two locations among 4 varieties of buckwheat and two different seeding rates.

II. MATERIALS AND METHODS

The trial was performed in 2015 in two locations in Umbria, in the province of Perugia, placed at different altitudes: Castelluccio di Norcia (about 1400 m a.s.l.) and Norcia (about 600 m a.s.l.). Four cultivars of buckwheat have been compared: Bamby, of Austrian origin; Spacinska, from Slovakia; Lileja, of Russian origin, and Castelrotto ecotype, from the province of Bolzano (South Tyrol) in Italian Alps. Two levels of seed density (300 and 400 viable seeds/m^2) have also been compared in a randomized block experimental design with three replicates. The first experimental field was set up in the locality Piano Perduto, on a sandy-clay loam soil from moraine disintegration, with a good amount of organic matter and precession of pasture. The other field was set up in Norcia basin in the locality Case Sparse, on a loam soil, with a meadow of mixed grasses and legumes as preceding crop.

The climate of the two locations was slightly diversified (see Fig. 1 and Fig. 2 for weather data) with cooler weather and more consistent rainfall during the crop cycle (May-September 2015) in Castelluccio. In Norcia there were more episodic precipitations with a slight water deficit. In both locations the temperatures have been higher than the average during the crop cycle, with maximum values above 30 °C during July 2015 in Norcia, leading to thermal stress for the culture.

The cultivation technique was the same in the two locations: ploughing at 20 cm depth, followed by harrowing to prepare the seed bed. The experimental fields were conducted both in organic farms and following organic farming without the use of synthetic fertilizers or other chemical products.

Before sowing the germination and the weight of 1000 seeds were evaluated, so as to obtain a uniform investment respectively of about 300 and 400 plants/m^2, corresponding approximately to 75 and 100 kg/ha of seed.

Sowing took place on 9 May 2015 in Castelluccio and on 13 May 2015 in Norcia.

During the crop cycle were carried out fortnightly surveys of various morphological characters such as the number of plants per m^2, the height and the number of branch stages of specimen plants. The harvest was made in both locations on 1 October 2015, picking apart before 1 m^2 by hand in each plot to determine the unitary production. On the sample from each plot were detected: the number of plants, the total sample weight, the medium plant height, the medium number of bunches and the medium weight of seeds per plant, the total grain weight, the weight of 1000 seeds and the test weight determined using a Schopper balance. Data were subjected to analysis of variance (ANOVA) using the SPSS software (Statistical Package for Social Sciences Inc., Chicago, IL, USA) for Windows (version 20.0) to verify the significance of the sources of variation (varieties, locations and seeding density); in the case of significant differences between the mean values, they were tested with the Tukey test for multiple comparisons.

III. RESULTS

In Tables 1, 2 and 3 the main data obtained with biometric measurements and on the occasion of the harvest are shown. The biometric parameters (plant height, number of branch stages per plant, percent index of surface area covering) were measured on 26 August 2015 at the phenological stage of grain ripening (about 30% of achenes browned), while the production data (final density, weight of seeds per plant, achene production per hectare, weight of 1000 achenes and test weight) were measured at harvest (1 October 2015).

The height of the plants was generally quite low, probably as a result of low rainfall recorded in the spring and summer of 2015. The tested varieties showed highly significant ($p \leq 0.01$) differences (Table 1), with Spacinska that was lower than other cultivars. A significant ($p \leq 0.05$) difference was also recorded between the different seeding densities (Table 3), with the higher density which determined a greater height because of increased intraspecific competition. No significant difference was instead measured between the two locations (Table 2).

The number of branch stages varied highly significantly as a function of the cultivar (Table 1), resulting higher in Bamby and lower in the other three cultivars. There were no significant differences between locations (Table 2) and between seeding densities (Table 3).

The index of surface area covering was not optimal, probably as a consequence of dry and hot climate, especially in Norcia. There were no significant differences between cultivars (Table 1), whereas there was a significant difference between locations, with better results in Castelluccio, and between densities of planting, with the highest density which predictably resulted in more coverage.

The final density of plants/m^2 was not affected significantly by cultivar (Table 1) or by location (Table 2), while it was significantly greater with the higher seed density (Table 3); however, the density in each case turned out to be much less than the number of viable seeds/m^2.

The weight of achenes per plant varied very significantly with the variety, with Lileja and ecotype Castelrotto who gave the highest results, Bamby that showed lower levels and Spacinska that produced the least amount of achenes per plant (Table 1). A highly significant difference was also recorded between locations, with a strong prevalence of Castelluccio (Table 2). Differences between the two seeding densities were not significant (Table 3).

The production of achenes per hectare also varied very significantly depending on the cultivar (Table 1), with the ecotype of Castelrotto that gave the best results, followed in order by Bamby, from Lileja and from Spacinska which was more detached. The difference between locations was significant (Table 2), with the higher yields recorded in Castelluccio. The differences between seed densities were not significant (Table 3).

The weight of 1000 seeds differed very significantly among all varieties (Table 1), with Lileja, Spacinska, ecotype Castelrotto and Bamby in descending order. Even the difference between locations proved highly significant (Table 2), with a better filling of the seeds, and thus a higher weight, registered in Castelluccio. The effect of seed density was not significant (Table 3).

The test weight varied highly significantly among the four varieties, with the highest value for the ecotype Castelrotto, followed by Bamby, Spacinska and Lileja (Table 1). Highly significant was also the difference between locations (Table 2), with a higher weight in Castelluccio, and between seeding densities, with the best results corresponding to the lower density (Table 3).

Pearson correlations between all the measured variables (plant height, number of branch stages per plant, percent index of surface area covering, final density of plants/m^2, average weight of achenes per plant, achene production per hectare, weight of 1000 seeds, test weight) were also verified (Table 4).

Among the biometric characters, plant height presented a positive and highly significant correlation ($p \leq 0.01$) with the number of branch stages/plant, the index of surface area covering and the weight of achenes/plant, and a positive and significant correlation ($p \leq 0.05$) with the production per hectare. The number of branch stages/plant showed a positive and highly significant correlation with the index of surface area covering and a negative and significant correlation with the weight of 1000 seeds. The index of surface area covering showed a positive and highly significant correlation with the final density of plants per m^2, the average weight of achenes/plant and the production per hectare.

Among the production variables measured at harvest, the final density of plants per m^2 showed a positive and highly significant correlation with the production per hectare and a negative and highly significant correlation with the weight of 1000 seeds. The average weight of achenes/plant showed a positive and highly significant correlation with the production per hectare and with the test weight. The production per hectare demonstrated a positive and highly significant correlation with the test weight and a negative and significant correlation with the weight of 1000 seeds. Finally, the weight of 1000 seeds showed a negative and highly significant correlation with the test weight.

IV. DISCUSSION

The factors of variation in the experimental field trial (variety, location, seeding rates) resulted in significant differences of great importance.

The four tested varieties all showed sufficient adaptation to the climatic conditions of the planting locations. The best overall results have occurred with the ecotype Castelrotto, native of South Tyrol, which recorded the highest yield and the greatest weight of seeds per plant. This variety was also characterized by a very high test weight, while the weight of 1000 seeds was medium-low, but this feature is highly dependent on the genotype and does not indicate in this case problems during maturation. Good results were also registered with Bamby cultivar, from Austria, which provided a slightly lower production, but not statistically different; data on the qualitative parameters confirmed the varietal characteristics already known (medium-high test weight, but a very low weight of 1000 seeds due to the small size of achenes); another feature confirmed in this test was the tendency to form a greater number of branch stages than other varieties [13]. The cultivar Lileja, originating in Russia, gave rise to medium productive results, with a high weight of seeds per plant and a trend of qualitative parameters confirming the varietal characteristics (low test weight, medium-high weight of 1000 seeds) [13]. The variety Spacinska, originally from Slovakia, provided the worst results, with smaller average height than the other cultivars, indicating a stress during the vegetative growth; these conditions continued even during the ripening of the achenes, leading to a reduced yield and a low weight of seeds per plant. The test weight was medium-low and the weight of the 1000 seeds was medium, respecting also in this case the trend of qualitative characters seen in other tests [14].

As for the locations, this trial confirmed the better adaptation of buckwheat to the climatic conditions of the mountains of central Italy compared to the places at lower altitude, already observed in other tests conducted in Tuscany [14]. In fact, in the location of Castelluccio were recorded a higher level of coverage, a greater yield per surface unit and an increased production of seeds per plant, and better quality parameters of grain (test weight, weight of 1000 seeds) that indicate an increased filling of the seed. All of this can be attributed to the higher rainfall of the site of Castelluccio, which allowed a more regular maturation of the achenes, and to lower summer temperatures, which favored the fruit setting.

The different density of sowing (300 and 400 viable seeds/m^2) influenced only some of the measured parameters, and in particular the average height, which was greater with the highest density, indicating greater competition between plants; the index of surface area covering and the final density of the plants, which, as expected, were higher with the higher density; and a test weight slightly greater, but with highly significant difference, with the lower density, that also in this case demonstrated less competition. There were no significant differences in the production per plant and in yield per surface unit; therefore it seems more advisable to use the lower dose seed, also in consideration of the high cost of the seed. The higher seeding density can be used in case of high presence of weeds to achieve an increased competitiveness of the crop.

As for the Pearson correlations detected between the variables, the significant ones were mainly positive, as the majority of them (plant height, number of stages per plant, index of surface area covering, final density of plants/m^2, seed weight per plant, production of achenes per hectare, test weight) are all indexes of a satisfactory vegetative state of the single plant or the whole plot. It was instead recorded a negative correlation between some of these variables (number of branch stages per plant, final density of plants/m^2, production of achenes per hectare) and the weight of 1000 seeds: this result, apparently surprising, can be explained by a best vegetative and productive response of varieties with small achenes (Bamby, ecotype Castelrotto) compared to those with large achenes (Lileja, Spacinska). The negative correlation, which is also unusual, between the weight of 1000 seeds and the test weight is explained by the varietal characteristics of achenes, in part already known [14], which were more rounded and regular in varieties with small achenes, resulting in a higher test weight.

V. CONCLUSIONS

The trial performed in 2015 (preceded by sowing in various places of the same region in 2014, which provided good results in all cases) showed good adaptation of buckwheat in hilly areas of Umbria. As noted in the course of multi-year studies conducted in the mountain district of Garfagnana [13, 14], buckwheat crop is more adapted to the environments at a higher altitude, enjoying during the summer a cooler and rainy climate, generally more suitable for the full expression of the potential of this species. The production data are placed in the average compared to crops produced under organic and low-input farming techniques, as they are in the normal range, compared to what was observed in previous studies, the quality parameters of the grain (test weight, weight of 1000 seeds). Therefore, buckwheat can be described as a suitable alternative species to be inserted in the crop systems of the hilly and mountainous environments of central Italy, avoiding the frequent recourse to monoculture or the too frequent repetition of the most profitable and most traditional crops in the various areas (lentil, emmer wheat, potato, etc.). In this study were also noted biometric and productive differences between the varieties under test, with the best results provided by accessions from the Alps (Bamby, Castelrotto ecotype) compared to those originating from Eastern Europe (Spacinska, Lileja). These data, however, need to be confirmed by further years of experimentation and are not in agreement with those obtained by other researchers [16], which reported high yields for Spacinska and Lileja and a lower production for Bamby in other locations of Central and Southern Italy. Other aspects that require further investigation are those related to the transformation of buckwheat in high value-added food products (including whole groats, bread, pasta, biscuits) that should be made by small enterprises in the local communities to determine a greater stimulation of the economy of the rural areas of Umbria and especially in mountain areas. Once clarified the technical issues relating to the transformation, it might lead to the establishment of a production chain comprising agricultural producers, processors and restaurateurs, and reaching at last the final consumer, with a positive impact also on the tourist offer and on the promotion of the various areas of the Umbrian Apennines. The opportunity to revitalize the economy of mountain areas is even more important following the earthquake that caused serious damage in many areas of Umbria (including the locations of this trial) in the summer and autumn of 2016.

ACKNOWLEDGEMENTS

The research was financed by Regione Umbria (Italy) through the project entitled “SARACENO-UMBRIA” under Action 1.2.4 of the Rural Development Program

(PSR) 2007-2013. Thanks are extended to the farm Coccia Sante Azienda Agricola of Norcia (project leader), where the experimental fields have been set up.

REFERENCES

[1] Campbell C. G. (1997): Buckwheat. IPGRI. Rome.
[2] Messedaglia L. (1931): A proposito di grano saraceno e di polenta: note manzoniane (in Italian). La Tipografica Veronese. Verona. Italy.
[3] Bonafaccia G., Acquistucci R., Luthar Z. (1994): Proximate chemical composition and protein characterization of the buckwheat cultivated in Italy. *Fagopyrum* 14: 43-48.
[4] Bonafaccia G., Gambelli L., Fabjan N., Kreft I. (2003): Trace elements in flour and bran from common and tartary buckwheat. *Food Chemistry* 83: 1-5.
[5] Steadman. K. J., Burgoon. M. S., Schuster. R. L., Lewis. B. A., Edwardson. S. E., Obendorf. R. L. (2001): Minerals. phytic acid. tannin and rutin in buckwheat seed milling fractions. *J. Sci. Food Agric*. 81: 1094–1100.
[6] Kreft I., Fabjan N., Yasumoto K. (2006): Rutin content in buckwheat (*Fagopyrum esculentum* Moench) food materials and products. *Food Chemistry* 98: 508-512.
[7] Steadman. K. J., Burgoon. M. S., Schuster. R. L., Lewis. B. A., Edwardson. S. E., Obendorf. R. L. (2000): Fagopyritols. D-chiro-inositol. and other soluble carbohydrates in buckwheat seed milling fractions. *J. Agric. Food Chem.* 48: 2843-2847.
[8] Zhang Z. L., Zhou M. L., Tang Y., Li F. L., Tang Y. X., Shao J. R., Xue W. T., Wu Y. M. (2012): Bioactive compounds in functional buckwheat food. *Food Res. Int*. 49: 389-95.
[9] Larner J. (2002): D-chiro-inositol-its functional role in insulin action and its deficit in insulin resistance. *Int. J. Exp. Diabetes Res.* 3(1): 47-60.
[10] Pintaudi B., Di Vieste G., Bonomo M. (2016): The effectiveness of myo-inositol and D-chiro inositol treatment in Type 2 diabetes. *Int J Endocrinol.* published online 11 Oct. 2016.
[11] Pizzo A., Laganà A.S., Barbaro L. (2014): Comparison between effects of myo-inositol and D-chiro-inositol on ovarian function and metabolic factors in women with PCOS. *Gynecol. Endocrinol.* 30(3): 205-8.
[12] Sofi F., Ghiselli L., Dinu M., Whittaker A., Pagliai G., Cesari F., Fiorillo C., Becatti M., Tallarico R., Casini A., Benedettelli S. (2016): Consumption of buckwheat products and cardiovascular risk profile: a randomized, single-blinded crossover trial. *J. Nutr. Food Sci.* 6(3): 501-509.
[13] Tallarico R., Ghiselli L., Romagnoli S., Benedettelli S., Pardini A. (2009): Evaluation trials of two buckwheat cultivars in Apennine mountains (Central Italy). *Fagopyrum* 26: 45-55.
[14] Ghiselli L., Tallarico R., Mariotti M., Romagnoli S., Baglio A. P., Donnarumma P., Benedettelli S. (2016): Agronomic and nutritional characteristics of three buckwheat cultivars under organic farming in three environments of the Garfagnana mountain district. *Italian Journal of Agronomy* 11 (3): 188-194.
[15] Brunori A., Brunori A., Baviello G., Marconi E., Colonna M., Ricci M. (2005): The yield of five buckwheat (*Fagopyrum esculentum* Moench) varieties grown in Central and Southern Italy. *Fagopyrum* 22: 98-102.
[16] Brunori A., Brunori A., Baviello G., Marconi E., Colonna M., Ricci M., Mandarino P. (2006): Yield assessment of twenty buckwheat (*Fagopyrum esculentum* Moench and *Fagopyrum tataricum* Gaertn.) varieties grown in Central (Molise) and Southern Italy (Basilicata and Calabria). *Fagopyrum* 23: 83-90.

Table.1: Biometric and production data in the different varieties of buckwheat.

Variety	Plant height cm	Branch stages/ plant	Surface area covering %	Final density plants/m^2	Seed weight/plant g	Yield t/ha	1000 seed weight g	Test weight kg/hL
Bamby	48.6a	8.0a	59.6	113.0	1.6b	1.78ab	18.4d	63.5b
Spacinska	44.0b	7.2b	42.5	95.6	1.1c	1.03c	23.1b	61.3c
Lileja	46.9a	7.4b	55.8	81.1	1.9a	1.50bc	24.2a	60.4d
Castelrotto ecotype	48.2a	7.3b	61.7	105.1	1.9a	2.01a	20.3c	65.3a
Significance	**	**	ns	ns	**	**	**	**

** = significant differences at $p \leq 0.05$, ** = significant differences at $p \leq 0.01$; ns = not significant. Different letters indicate significantly different data.*

Table.2: Biometric and production data in the different test locations.

Location	Plant height cm	Branch stages/ plant	Surface area covering %	Final density plants/m^2	Seed weight/plant g	Yield t/ha	1000 seed weight g	Test weight kg/hL
Castelluccio di Norcia	47.6	7.7	58.1	99.8	1.8	1.72	22.2	63.4
Norcia	46.2	7.3	51.7	97.6	1.5	1.44	20.8	61.9
Significance	ns	ns	*	ns	**	*	**	**

** = significant differences at p≤0.05, ** = significant differences at p≤0.01; ns = not significant. Different letters indicate significantly different data.*

Table.3: Biometric and production data for the different seed densities.

Density	Plant height cm	Branch stages/ plant	Surface area covering %	Final density plants/m^2	Seed weight/plant g	Yield t/ha	1000 seed weight g	Test weight kg/hl
300 seeds/m^2	46.0	7.3	51.7	90.2	1.6	1.47	21.7	63.0
400 seeds/m^2	47.8	7.6	58.1	107.2	1.6	1.69	21.3	62.3
Significance	*	ns	*	*	ns	ns	ns	**

** = significant differences at p≤0.05, ** = significant differences at p≤0.01; ns = not significant. Different letters indicate significantly different data.*

Table.4: Pearson correlations between the variables.

	Plant height	Branch stages/plant	Final density	Seed weight/plant	Surface area covering	Yield	1000 seed weight	Test weight
Plant height	1	0.713**	0.123	0.412**	0.553**	0.327*	-0.280	0.204
Branch stages/ plant	0.713**	1	0.071	0.133	0.399**	0.104	-0.297*	0.097
Final density	0.123	0.071	1	-0.038	0.387**	0.776**	-0.405**	0.160
Seed weight/plant	0.412**	0.133	-0.038	1	0.496**	0.577**	-0.030	0.437**
Surface area covering	0.553**	0.399**	0.387**	0.496**	1	0.600**	-0.242	0.202
Yield	0.327*	0.104	0.776**	0.577**	0.600**	1	-0.366*	0.418**
1000 seed weight	-0.280	-0.297*	-0.405**	-0.030	-0.242	-0.366*	1	-0.490**
Test weight	0.204	0.097	0.160	0.437**	0.202	0.418**	-0.490**	1

** = significant differences at p≤0.05, ** = significant differences at p≤0.01.*

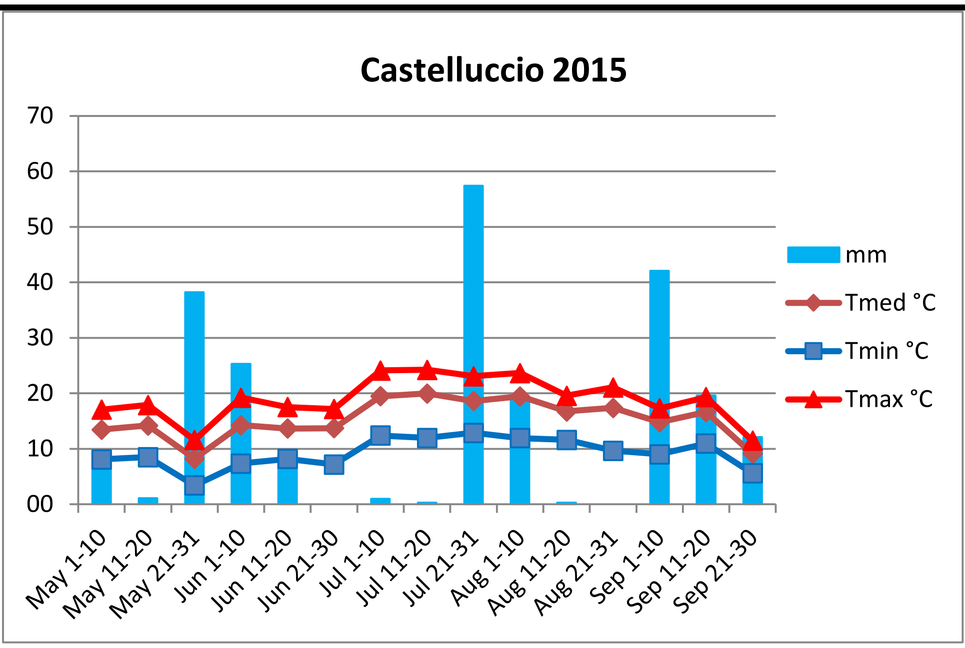

Fig. 1: Meteorological trend during 2015 growing season (May-September) at Castelluccio di Norcia (Umbria, Italy). mm = decadal rainfall in mm; Tmed, Tmin, Tmax = decadal averages of daily medium, minimum and maximum temperature in °C.

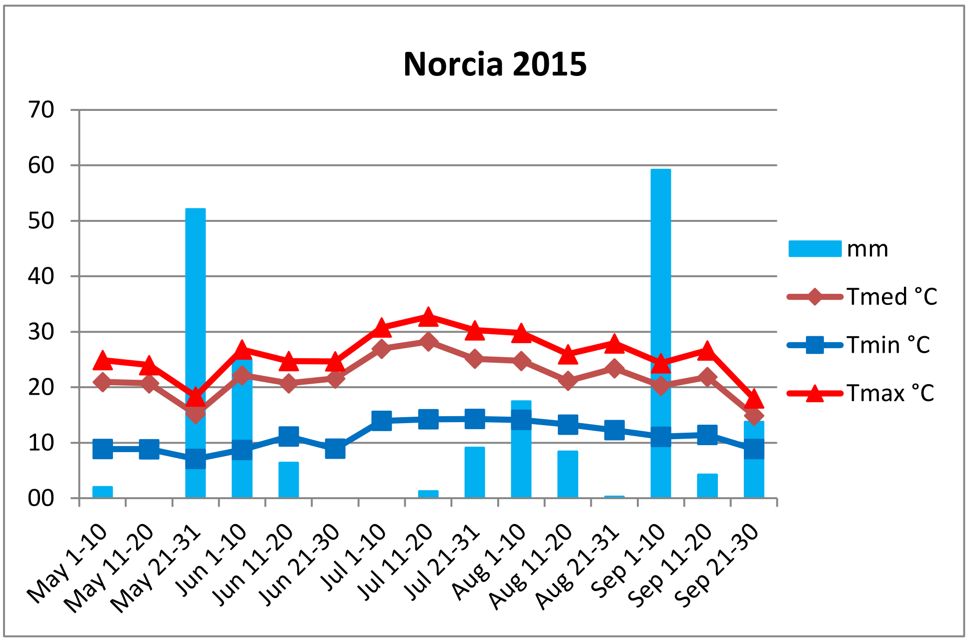

Fig.2: Meteorological trend during 2015 growing season (May-September) at Norcia (Umbria, Italy). mm = decadal rainfall in mm; Tmed, Tmin, Tmax = decadal averages of daily medium, minimum and maximum temperature in °C.