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Crambe abyssinica a non-food crop with potential for the Mediterranean climate: Insights on productive performances and root growth

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A B S T R A C T

Within a framework of renewed interest in crambe (*Crambe abyssinica* Hochst ex R.E. Fries) sourcing raw materials for the bio-based industry, the adaptability and productive performances of this oil crop have been evaluated under contrasting Mediterranean environments (i.e., a fertile site in the northern part of Po valley vs. a semi-arid site of southern Sicily) during two consecutive growing seasons, aiming at its possible stable introduction in this area. The trial set in northern Italy compared three commercial varieties of crambe (Galactica, Nebula and Mario) in spring sowing, while in southern Italy only the var. Mario was tested with autumn sowing. Regardless of location and variety, thermal time for maturity was quite stable (1200–1400 °C), and the crop provided satisfactory seed yields (grand mean 2.29 Mg hulled seeds ha^{-1}), with average oil content of ~400 g kg^{-1} (on dehulled seeds) and ~52% of erucic acid. Significantly higher seed and oil yields were reached in northern than in southern Italy. Furthermore, crambe thermal use efficiency (THUE) was also higher in the north than in the south, possibly due to better environmental adaptability of the crop. The limited intraspecific variability within crambe was confirmed, with better productive performances showed by the domestic selection Mario. Promising traits were revealed in Nebula, showing greater seed weight, root length density and area, and thinner roots, although the root growth of crambe was generally modest compared with modern high erucic acid rapeseed hybrids. Available crambe varieties could be efficiently included in crop rotations across a wide range of environments within the Mediterranean basin. The short growth cycle represents an outstanding added value for this species, allowing the avoidance of prolonged drought and heat stress typical of late spring/early summer months under the Mediterranean climate. However, increased yields are needed to meet the market requests; nonetheless, the little genetic variability suggests that there is large scope for future breeding improvements, maybe exploiting advanced techniques to improve the existing genetic resources.

1. Introduction

The most widely cultivated oilcrops mainly contain five fatty acids in their oil, which differs in relative proportions depending on species, i.e., palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2) and α-linolenic acids (C18:3) (Carlsson et al., 2011). This means that the oleochemical industry is steadily searching for new sources of uncommon fatty acids for specific applications. High-erucic acid (C22:1) oils are potential raw materials for both oleochemical transformation and direct use in producing erucamide – a slip agent enabling manufacture of extreme-temperature resistant plastic films (Walker, 2004). High erucic acid rapeseed (HEAR) (*Brassica napus* L. var. *oleifera* Metzg) has been the most common "green" source of erucic acid so far, in view of its good yield and adaptability to a variety of environments. This has intensified specific breeding programmes, making several winter HEAR varieties available on European markets in recent years, together with the latest composite hybrid hybrids (CHH) (Zanetti et al., 2009a), now cultivated in the continental climates of central Europe. In warmer and semi-arid environments, inter-

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esting and alternative sources of erucic acid are *Brassica carinata* A. Braun, *Brassica juncea* L. Czern and *Crambe abyssinica* Hochst ex R.E. Fries, all characterised by limited frost resistance. *Crambe abyssinica* (crambe) is particularly interesting, as its oil contains greater amounts of erucic acid than HEAR (≥55% vs. ∼50%) (Bondioli et al., 1998; Lazzeri et al., 1994; Temple-Heald, 2004). Crambe was first studied a few decades ago (Laghetti et al., 1995; Lazzeri et al., 1994, 1995; Lessman, 1990; Meijer et al., 1999; Vollmann and Ruckenbauer, 1993; Zanetti et al., 2006), but its cultivation in Europe still remains limited (Fontana et al., 1998; Zanetti et al., 2013). Currently, there is a renewed interest toward this species, as demonstrated by several European projects recently funded within the Seventh Framework Programme (FP7) (e.g., ICON, EPOBIO) and Horizon 2020 (e.g., COSMOS). Some of these projects aimed in particular at improving the oil profile, to achieve further increases in erucic acid contents, with a target rate exceeding 66%, partly with GM breeding techniques (Chhikara et al., 2012; Li et al., 2012; Napier et al., 2014).

Native to the Mediterranean basin (Leppik and White, 1975), crambe has favourable agronomic traits such as short growing cycle (Golz, 1993), tolerance to drought, good adaptability to poor sandy soils, and natural resistance to insects (Anderson et al., 1992; Kmec et al., 1998). In addition, it has indehiscent pods, which prevent shattering and seed loss, unlike HEAR which may be subjected to significant yield losses, especially in the Mediterranean environment, as a consequence of sudden decreases of the atmospheric humidity at maturity.

Despite these favourable traits, crambe is not able to tolerate low temperatures (Leppik and White, 1975; Papathanasiou et al., 1966; Wang et al., 2000) nor water logging, so that only spring sowing can be applied in continental European regions with winter temperatures falling to −7 °C. In southern Mediterranean regions crambe adapts well to late autumn sowing (i.e., late November, early December), like winter wheat, but in view of its shorter growing cycle, harvesting usually takes place more than one month prior to winter cereals, thus avoiding the occurrence of prolonged drought and heat stress typical of late spring/early summer months. In view of the possible stable introduction of crambe in the Mediterranean basin, and considering the limited number of studies conducted in this area (Fontana et al., 1998; Laghetti et al., 1995; Lazzeri et al., 1995), a two-year field trial was carried out in two contrasting environments: at Legnaro (Padova, North Italy), and at Pozzallo (Ragusa, South Italy), with the aim of investigating productive potential of this species and at identifying possible significant constraints. In both locations, phenological stages and productive traits were recorded together with climatic variables in order to estimate the thermal use efficiency of a common variety grown in the two environments. In addition, a full characterisation of the root system of three commercial European varieties was carried out in northern Italy together with their productive and qualitative performances.

2. Materials and methods

2.1. Tested varieties

Three commercial varieties of crambe, Nebula and Galactica, both selected by DLO – Wageningen (NL), and Mario, patented by the Agricultural Research and Economic Study Council – CREA (Bologna, I), were cultivated in open fields for two years in NE Italy, whilst in the southern Italy location only Mario was tested for two subsequent growing seasons. The two “*Dutch*” varieties were selected for their adaptability to the central European environment and were based on F8 selection starting from a common parent, P2 (Mastebroek and Lange, 1997), crossed with “*American*” P1 for Galactica and P3 for Nebula, respectively. According to the origin of the parents, these varieties can be referred to a “*Dutch* × *American*” background for Galactica, and “*American*” only for Nebula (see Mastebroek and Lange, 1997 for further details). Instead, var. Mario was derived from the accession ‘BelAnn’, unlike P2 and P3, and improved for Mediterranean environmental conditions (Lazzeri L., pers. comm.).

Table 1
Main physical and chemical characteristics of the soils in two experimental sites in the north (Legnaro, PD) and south (Pozzallo, RG) of Italy.

Parameter		Northern Italy	Sourthern Italy
Sand[a]	%	28.6	37.0
Loam[a]	%	56.6	25.0
Clay[a]	%	14.8	38.0
pH (in water)		8.4	8.5
Organic matter[b]	%	2.5	2.6
Total N[c]	$mg\,g^{-1}$	0.9	1.6
Available P[d]	$\mu g\,g^{-1}$	35.5	52.3
Available K[e]	$\mu g\,g^{-1}$	117	325.5
Total S[f]	$\mu g\,g^{-1}$	61.0	NA

NA: data not available.
[a] Gattorta (Lotti and Galoppini, 1980).
[b] Walkley and Black (AOAC, 1990).
[c] Kjeldahl (AOAC, 1990).
[d] Ferrari (AOAC, 1990).
[e] Dirks & Scheffer (AOAC, 1990).
[f] AOAC (1990).

2.2. Field trial set-up

2.2.1. Northern Italy

Field trials were carried out at Legnaro (45°21′N, 11°58′E, 12 m a.s.l., NE Italy) in two consecutive years (2006, 2007) in a fertile silty-loam soil with sub-alkaline pH (Table 1), according to a completely randomised block design with three replications ($n = 3$). The large plot size (∼400 m^2) allowed agronomic practices to be managed with farm-scale equipment. The soil was ploughed to a depth of 0.3 m in autumn and harrowed in spring, immediately before sowing. In both years, sowing took place in early spring (March) by means of a mechanical seeder (Gaspardo, Italy), commonly adopted for small cereals, and harvest about three months later (late June) (Table 2). Limited amounts of fertilisers, i.e., 30, 40 and 75 kg ha^{-1} of N, P and K, respectively, were applied before sowing and incorporated by harrowing. The inter-row distance was 0.23 m and the amount of seeds 18 kg ha^{-1}, almost double than recommended, because of the low germination rate of crambe seeds (∼ 50%). This amount corresponded to ∼250 viable seeds m^{-2}, which provided a final plant density of ∼75 plants m^{-2}, for all plots. During the crop cycle, there was no need of either weed or pest control. Main phenological stages were recorded, i.e., emergence, flowering and maturity in each growing season. Plots were entirely harvested at maturity with a Lexion 600 combine harvester equipped with a V600 cutting bar (CLAAS KGaA mbH, Westphalia, D). Plot yield (hulled: seed + capsule) was reported as dry weight (DW) on a hectare base, taking into account seed moisture determined after oven-drying of samples at 105 °C.

2.2.2. Southern Italy

Field trials were carried out at Pozzallo (36°44′N, 14°45′E, 10 m a.s.l., SE Italy) in two consecutive growing seasons (2006–07 and 2007–08, hereinafter referred as 2006 and 2007, respectively) in a red soil of calcareous matrix with sub-alkaline pH (Table 1), according to a completely randomised block design ($n = 3$) with single plot size of 4.0 × 3.0 m. The soil was ploughed to a depth of 0.3 m in early summer and harrowed before sowing. In both years, sowing took place in late autumn (end of November) and harvest in late spring (about mid-May) (Table 2). Mineral perphosphate and