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# Selenium-enriched durum wheat improves the nutritional profile of pasta without altering its organoleptic properties

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ABSTRACT

Two field experiments were conducted over three growing seasons (2006–07, 2008–09 and 2009–10) to evaluate Se-enriched pasta through foliar fertilization at various rates and timing of application on 4 durum wheat varieties. Our findings confirm the effectiveness of foliar Se fertilization to increase Se concentrations in durum wheat grain, even at high Se rates (120 g Se $ha^{-1}$). Se fortification was significant across different genotypes, with greater Se accumulation in landraces ('Timilia') and obsolete varieties ('Cappelli'), with respect to modern varieties. The Se content in the grain was increased by up to 35-fold that of the untreated control. The Se concentration decreased during milling (11%), while processing and cooking of pasta did not show significant decreases. This biofortification stategy had no effects on grain quality parameters, except for reduced gluten index in the high-gluten variety PR22D89, as well as for the sensorial properties of the spaghetti.



## 1. Introduction

Over the last few decades, food consumption has changed dramatically. Today, foods are not intended to only satisfy the basic human needs, but also to promote health, prevent diseases, and improve the physical and mental conditions of consumers. Numerous studies have demonstrated that nutrition has a crucial role in the prevention of chronic diseases, as most of these can be related to diet. Selenium (Se) is an essential trace element that has biological functions of great importance for human health. The importance of this micronutrient is mainly due to its incorporation into proteins, as the constitutive part of the 21st amino acid, selenocysteine (Roman, Jitaru, & Barbante, 2014). Se-proteins participate in antioxidant defense and redox state regulation, and in more specific biological processes (Roman et al., 2014). Even if there is little knowledge of the precise biological significance of Se in humans, a large number of studies have associated positive effects of Se levels with prevention/mitigation/inhibition of several human diseases (e.g., type 2 diabetes, cancers, endocrine disorders, cardiovascular diseases, neurological disorders, male infertility) (Hatfield, Tsuji, Carlson, & Gladyshev, 2014; Vinceti et al., 2014).

In contrast to many other micronutrients, the intake of Se varies hugely worldwide, due to the global variations in Se soil content and the related variability in Se content of foods (Rayman, 2012). Generally inadequate Se intake is associated with areas where Se

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concentrations in the soil are low, which is reflected in the lower Se content in cereals and vegetables (Spadoni et al., 2007). Suboptimal Se status was reported to be widespread throughout the Europe, the UK and the Middle East, and these results agreed with previous reports highlighting the problem (Stoffaneller & Morse, 2015). Indeed, the link between the Se concentration of wheat grain and dietary Se intake has been demonstrated previously in other countries (e.g. in the UK; Broadley et al., 2010).

In relation to the optimal Se levels in the human diet, the European Recommended Dietary Allowance (RDA) of Se for humans was estimated at 55 mg Se $day^{-1}$ (Niedzielski et al., 2016). Several studies have gone further, and following clinical trials, these have recommended a regular oral dose of 200 mg Se $day^{-1}$ to preventor reduce incidence of a number of human diseases (Reid et al., 2008).

Potential solutions for increasing Se intake have included agronomic and genetic biofortification (Hawkesford & Zhao, 2007). Agronomic biofortification of crops with Se through foliar and soil application is the most commonly used practice (Curtin, Hanson, Lindley, & Butler, 2006), and bread wheat is the main cereal that has been selected for this approach (Hart et al., 2011; Lazo-Vélez, Chávez-Santoscoy, & Serna-Saldivar, 2014; Lyons, Ortiz-Monasterio, Stangoulis, & Graham, 2005; Zhao et al., 2009). Several studies have shown that selenite ($Na_2SeO_3$) is adsorbed much more strongly than selenate ($Na_2SeO_4$) in different soils, and thus the selenate form is more available to the plant (Nawaz et al., 2015). Therefore, the difference in Se mobility and its availability to plants explains the greater efficiency of Se fertilization with sodium selenate rather than sodium selenite in various species of cultivated plants (Longchamp, Castrec-Rouelle, Biron, & Bariac, 2015) and cereals (Stadlober, Sager, & Irgolic, 2001). However, for a given crop species, if genetic variability studies provide information about the extent of Se accumulation, and if this variation is heritable, traditional breeding programmes could be developed that would provide an alternative to agronomic biofortification and thus minimise the need to use Se (Lyons et al., 2005). Durum wheat (*Triticum durum* Desf.) is the main cereal crop in several countries of the Mediterranean basin mainly used for pasta, bread, and couscous production and so this could be a major dietary source of Se, especially in the framework of the Mediterranean diet.

Information related to the uptake of Se in durum wheat and its derived products of bran, semolina, and fresh and dried pasta appears to be limited. Only recently, studies performed in Portugal and Spain have suggested the effectiveness of Se fertilization also for this species (Galinha et al., 2013; Poblaciones, Rodrigo, Santamaría, Chen, & McGrath, 2014a). To ensure these levels of Se in the human organism, it is necessary to define the optimal Se fertilization timing and rate for durum wheat that also takes into account the possible losses that can occur during the processes of milling, pasta making, and cooking. It is well known that the concentration of vitamins and minerals are altered by the various processing methods, including milling, extrusion, and thermal processing. Generally, it is assumed that the milling process removes many of these components because most of them are concentrated in the outer layer of the grain (Cubadda, Aureli, Raggi, & Carcea, 2009; Lyons et al., 2005). Conversion of whole grain wheat to semolina can thus result in 40–80% loss of iron, zinc, copper, and magnesium (Cubadda et al., 2009; Lyons et al., 2005). Minerals, unlike vitamins, are not destroyed by heat, light, oxidizing agents or pH, although significant variations can occur through food processing/cooking (Khanam & Platel, 2016).

With regard to products derived from durum wheat, preliminary studies on the losses of Se with milling and processing have focused mainly on the pasta (Cubadda et al., 2009; Poblaciones et al., 2014a). To the best of our knowledge, there have not been any studies that have followed an integrated approach, with an assessment of the effects of Se biofortification from the agronomic levels to the pasta processing and cooking, which have included the organoleptic and sensory properties of the enriched pasta.

In the present study, two field experiments were conducted over three growing seasons with the objective to evaluate the development of a Se-enriched pasta through a protocol of foliar fertilization of durum wheat. In particular, we aimed to determine whether: (i) foliar application of Se is also effective in durum wheat, as it is in bread wheat, also considering different varieties released over different historical periods (i.e., old and modern varieties); (ii) the most important durum wheat attributes (i.e., grain yield, qualitative traits) are affected by Se application; (iii) the removal of the bran fraction during milling significantly reduces the concentration of Se in the semolina, as is the case for most of minerals; and (iv) the preparation and cooking of fresh and dried pasta result in further loss of Se from the final product.

The success of biofortified staple crops also depends on whether they are accepted and consumed by the target population. Thus, in the present study, the effects of Se enrichment on the sensory (organoleptic) properties of the final product were also considered, through the measurement of the various sensory attributes of the biofortified pasta compared with conventional pasta (e.g., taste, aroma, appearance, texture, cooking quality).

## 2. Materials and methods

### 2.1. Study site and crop husbandry

Two correlative field experiments were carried out at the *Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria – Centro di Ricerca per la Cerealicoltura* (CREA–CER) of Foggia, Italy (41° 28′N, 15° 32′E; 75 m a.s.l.) on a clay-loam soil (Typic Chromoxerert) over three growing seasons (2006–2007, 2008–2009, 2009–2010). The soil pH in this experimental site was 7.8 and the total selenium content was 130 μg $kg^{-1}$ within the normal range 10–200 μg Se $kg^{-1}$ of most soils in the world but higher than the mean value reported by Spadoni et al., 2007 for this area (40–70 μg $kg^{-1}$).

The first was an experimental field trial to determine the responses to different rates and timing of sodium selenate application, and the second was conducted at the farm level to determine the varietal responses to a single rate and timing Se application, and to evaluate the impact of pasta-making and cooking on the Se concentration in fresh and dried pasta. The previous crop grown on both experiments was durum wheat, and the seedling density was 350 seeds $m^2$. Fertilizer applications were made as in normal practice, at pre-sowing (36 kg N $ha^{-1}$; 92 kg P $ha^{-1}$ as ammonium bi-phosphate) and as top dressing (52 kg N $ha^{-1}$ as ammonium nitrate) at Zadoks growth stages (GS) 2.2 and 3.1, respectively (Zadoks, Chang, & Konzak, 1974). In both experiments, the weeds were controlled through the growing seasons with the herbicides Tralcossidim (1.7 L $ha^{-1}$), Clopiralid + MCPA + Fluroxypyr (2.0–2.5 L $ha^{-1}$). The mean yearly temperatures during the three growing seasons were quite different if compared to the long-term (56-year, from 1955 to 2010) means. The mean temperature of the first growing season was higher (14.2 °C) than the long-term mean (13.0 °C), whereas the mean temperatures of the second and third growing season were lower (12.5 and. 12.1 °C for 2008–09 and 2009–10, respectively). Rainfall during the growing period (from October to the end of June) in 2006–07 was lower (404.2 mm) than in 2008–09 (649.0 mm) and 2009–10 (535.8 mm). However, if considering the homogeneous distribution of rainfall during the whole study period and the mean rainfall over the long-term period (428 mm), it is likely that the crops did not experience water stress (either drought or excess) except for a limited waterlogging event in 2008–09 due to an amount of 153.5 mm of rainfall recorded in January.