Biofumigation potential of brassicas

II. Effect of environment and ontogeny on glucosinolate production and implications for screening

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Abstract

Biofumigation refers to the suppression of soil-borne pests and pathogens by biocidal compounds released by Brassicaceous green manure and rotation crops when glucosinolates (GSLs) in their tissues are hydrolysed. We investigated the effect of environment and ontogeny on the GSL production, and thus biofumigation potential, of eight entries from five Brassica species. The environments included autumn and spring sown field plots (FA and FS) and potted plants grown under ambient conditions (PAM) or in a temperature controlled glasshouse at 20 °C/12 °C (PTC). GSL concentration was measured in the root and shoot tissue at buds-raised, flowering and maturity. Of particular interest was the suitability of the pot-grown plants for screening large numbers of brassicas for GSL production. The type of GSLs present in the tissues and their relative proportions remained relatively constant across environments and at different growth stages, with the exception of an increase in indolyl GSLs in the FS environment suspected of being induced by insect attack. Total GSL concentration generally declined from buds-raised to flowering in all environments, and was lowest at maturity. The exceptions were B. campestris, which had higher GSL concentration at flowering than at buds-raised, and the PTC environment in which most species also showed an increase at flowering. Despite GSL types and their proportions remaining relatively constant, the total GSL concentration in the root and shoot tissue of all entries varied significantly with environment (3–10-fold) and was generally ranked FS>PAM>FA>PTC. Interactions between species and environments meant that the ranking of the Brassica entries for total shoot and root GSL concentration changed with environment. However within three entries from B. napus, the ranking was consistent across the environments. The added effect of environment on phenological development and biomass production further influenced GSL production (the product of GSL concentration and biomass) on a ground area basis. The results suggest that glasshouse environments can be used to determine the types and proportions of GSLs present, and to rank entries within, but not between species for the total concentration in the tissues. However the influence of the environment on both GSL concentration and biomass production suggests that an accurate estimate of GSL production on a ground area basis to assess biofumigation potential will require measurement in the target environment.

Introduction

Brassica green manure, rotation crops or seed meal amendments have been reported to suppress pest and disease organisms when grown or incorporated in the soil (e.g. Chan and Close, 1987; Mojtahedi et al., 1991). These effects are generally attributed to biocidal compounds released into the soil when glucosinolates (GSLs) in the incorporated tissues are hydrolysed. Isothiocyanates (ITCs) are the most toxic of several hydrolysis products and are known to have broad biocidal activity (reviewed by Brown and Morra, 1997; Chew, 1988; Fenwick et al., 1983; Rosa et al., 1997). ‘Biofumigation’ is a term recently used to describe this suppression of soil-borne pests and pathogens by Brassica rotation or green manure crops (Angus et al., 1994; Kirkegaard et al., 1993).
Interest in biofumigation has increased recently in horticultural industries because of restrictions on several synthetic pesticides and soil fumigants (e.g. methyl bromide, ethylene dibromide) and in broad-acre cereal cropping for suppression of soil-borne fungal pathogens (Angus et al., 1991; Kirkegaard et al., 1996). Enhancing biofumigation will require identification of brassicas which produce sufficient quantities of GSLs so that the ITCs released are effective in pest suppression.

There are about 20 different types of GSLs commonly found in brassicas. These vary in their structure depending on the type of organic side chain (aliphatic, aromatic or indolyl) on the molecule. The types, concentration and distribution of these GSLs is known to vary within and between Brassica species, and with plant age and growing conditions. Climatic, edaphic and biotic factors have all been reported to influence the GSL concentration in Brassica tissues (Rosa et al., 1997). Environmental factors such as daylength and temperature also influence the phenology and biomass production of brassicas (Nanda et al., 1996). As a result, the total production of GSL on a ground area basis (the product of GSL concentrations × biomass), and therefore biofumigation potential, will be significantly influenced by growing conditions.

These effects have implications for the selection of a suitable screening environment to assess the GSL production and biofumigation potential of a large number of diverse Brassica entries. Glasshouse studies using potted plants have the advantage that large numbers of entries can be screened under uniform and repeatable conditions. However it is important that the environment chosen for screening the brassicas gives results consistent with that in the intended field situation. Depending on specific objectives of the investigations, this may mean the glasshouse environment should provide either a qualitative assessment of the GSL profiles, a ranking of entries for GSL concentration, or an accurate estimate of GSL production (GSL concentration × biomass).

Few previous studies investigating pest suppression by Brassicaceae amendments have reported the GSL type or amounts produced by the incorporated tissue, nor considered how they may be influenced by growing conditions and the stage at which they were incorporated. In the first paper of this series (Part I, Kirkegaard and Sarwar, 1998), we reported the range of mid-flowering GSL production in the roots and shoots of 76 diverse Brassica and related species grown at one field site, and presented a framework for considering the components of GSL production and how they varied within and between species. In this study, a subset of those lines was grown in different environments, including pot-grown plants in the glasshouse, and were sampled at three phenological stages to determine GSL production. The objectives were: (1) to determine the effect of environment and ontogeny on components of GSL production, and (2) to determine the suitability of glasshouse environments to screen brassicas for biofumigation potential by comparing GSL types, concentration and production in the glasshouse with those in the field. A subsequent paper (Part III) reports the relative toxicity of the major GSL hydrolysis products to a range of soil-borne cereal pathogens (Sarwar et al., 1998).

Materials and methods

Brassica species

The brassicas used in the study are listed in Table 1. Most of the seed was obtained from the Australian Temperate Field Crops Collection at the Victorian Institute for Dryland Agriculture (VIDA), Horsham, Australia. The B. juncea lines came from the CSIRO Plant Industry B. juncea breeding program which has produced lines with low seed GSL levels (Oram and Kirk, 1992). The eight brassicas included B. napus olifera annua (spring canola) and B. juncea lines with high and low seed GSL content.

Growing environments

The four growing environments were: (1) field – autumn sown (FA), (2) field – spring sown (FS), (3) pots in open cold frames (PAM), and (4) pots in a temperature-controlled glasshouse (PTC). The details of these environments are summarised in Table 2.

Field site

Characteristics of the soil at the field site and the agronomic management of the field plots are given in the previous paper (Kirkegaard and Sarwar, 1998). Briefly, the seedlings were established in trays of moist vermiculite/peat until the 3rd leaf stage, and then transplanted into field plots 0.5 m × 1 m with 0.1 m inter-row and intra-row spacing (100 plants m⁻²). Three replicates of each entry were arranged in a randomised complete block design. The autumn and spring sowings were on adjacent blocks and were...