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The intrinsic quality of brassicaceous vegetables: How secondary plant metabolites are affected by genetic, environmental, and agronomic factors

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ABSTRACT

From the order Brassicales, different plant organs, such as inflorescences (e.g. broccoli and cauliflower), leaves (e.g. kale and pak choi), heads (e.g. white and red cabbage), as well as roots and bulbs (e.g. radish and turnip), are frequently consumed brassicaceaous vegetables. The order Brassicales is characterized by a specific group of secondary plant metabolites, namely the glucosinolates. Glucosinolates and their breakdown products the isothiocyanates are linked to conferring beneficial health effects. In addition, some studies have also highlighted the beneficial health effects of phenolic compounds and carotenoids, both well-known as antioxidants. Of interest is that the profiles and concentrations of secondary plant metabolites vary enormously between the species, and genetic factors are thought to affect this the most. Further, environmental and agronomical factors are also known to change concentrations of secondary plant metabolites enormously. The main physiological mechanism to produce secondary plant metabolites is defense. Thus, the intrinsic quality, including color, aroma, taste, and beneficial health properties of brassicaceous vegetables, is remarkably affected by secondary plant metabolite profiles and concentrations.

1. Introduction

Recently, long since forgotten or even new cultivars of well-known vegetables, such as violet kohlrabi or violet, yellow, and orange cauliflowers have enjoyed resurgence. The biodiversity of such vegetables is not only visible in its outer appearance, but is also based on their genetic diversity, which affects the profiles and concentrations of secondary plant metabolites. This diversity in the plant's morphology and biochemistry is essential for the plant's interaction with its environment and the various profiles and concentrations of secondary plant metabolites also have profound consequences for human health. The group of brassicaceous vegetables, formerly referred to as cruciferous vegetables, is a diverse one with respect to the different plant organs consumed, which include inflorescences (e.g. broccoli and cauliflower), leaves (e.g. kale and pak choi), heads (e.g. white and red cabbage), as well as roots and bulbs (e.g. radish and turnip). Furthermore, the profiles and concentrations of secondary plant metabolites vary enormously within the order of Brassicales that includes numerous brassicaceous vegetables.

1.1. Quality attributes of brassicaceous vegetables

The International Organization of Standardization (ISO) defines the quality of a product as "the sum of all characteristics, properties, and attributes which aimed at fulfilling the established or presumed customer requirements" (ISO 8402, 1989). A product is characterized by its intrinsic (e.g. color, aroma, taste, secondary plant metabolite profiles and concentrations) and extrinsic (e.g. packaging, brand name, country of origin, kind of production) quality features. However, consumers differ in their demands and desires as well as in socio-economic backgrounds (Schreiner et al., 2013). Therefore, defining intrinsic quality for brassicaceous vegetables is not simple.

Most vegetables are rich in various secondary plant metabolites that can be subdivided into several groups depending on the metabolite's chemical structure and functional properties: carotenoids and chlorophylls, glucosinolates, monoterpenes, phenolic compounds (polyphenols), phytic acid, phytoestrogens, phytosterols, protease inhibitors, saponins, and sulfides. Some of these secondary plant metabolites occur ubiquitously in the entire plant kingdom, and thus, in all types of vegetables, such as the large and very diverse group of phenolic compounds or the carotenoids; whereas other secondary plant metabolites are restricted to some botanical orders or families. Thus, sulfides are

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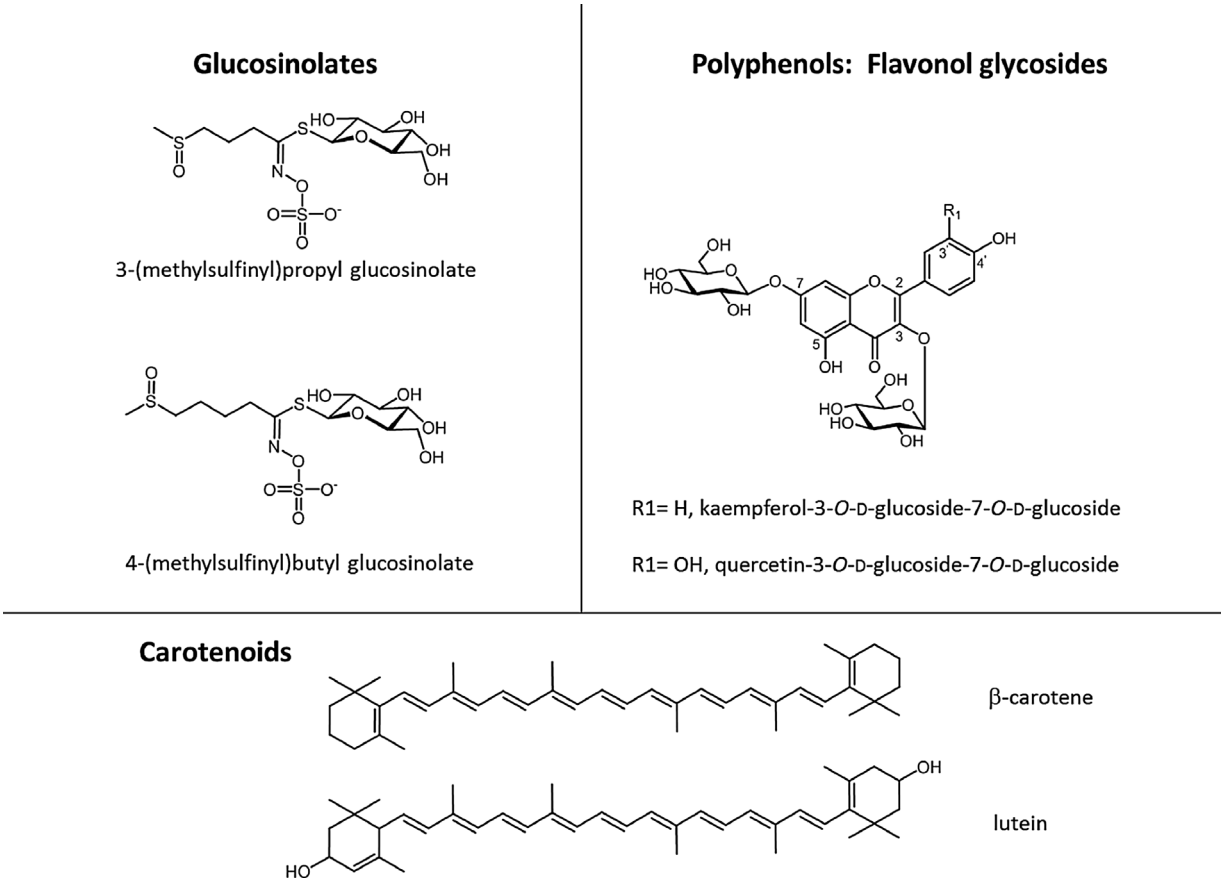

Fig. 1. Chemical structure of the main glucosinolates, polyphenols and carotenoids that occur in brassicaceaous vegetables.

found, next to Alliaceae and some other families, in Brassicaceae, and glucosinolates are found mainly in species belonging to the plant order of Brassicales.

Brassicaceous vegetables belong to the order Brassicales and most of them are members of the Brassicaceae family. About 12% of the world-grown vegetables are *Brassica* vegetables (FAOSTAT, 2017), illustrating the great importance of this vegetable family. Two especially common groups of brassicaceous vegetables are *Brassica oleracea* (broccoli, Brussels sprouts, white and red cabbage, cauliflower, collards, kale, and kohlrabi) and *Brassica rapa* (Chinese cabbage, pak choi, and turnips). A number of other species in the order Brassicales are also edible such as spider plant, moringa, and the common radish. Brassicaceous vegetables contain high levels of vitamins C, E, and K, as well as folate and minerals (Miller-Cebert et al., 2009) and dietary fiber (Tanongkankit et al., 2012). In addition to phytochemicals, such as carotenoids (Fig. 1) and phenolic compounds (Fig. 1), which occur in considerable amounts in some species, brassicaceous vegetables also contain sulfur-containing compounds e.g. methylcysteinsulfoxide and glucosinolates (Fig. 1, Table 1) (Mc Naughton and Marks, 2003; Verkerk et al., 2009b) which are responsible for the pungent and bitter taste or the spicy flavor of brassicaceous vegetables (Baik et al., 2003; Beck et al., 2014; Groenbaek et al., 2016).

1.1.1. Glucosinolates

The order Brassicales is characterized by a specific group of secondary plant metabolites, namely the glucosinolates (Clarke, 2010; Fahey et al., 2001; Verkerk et al., 2009b). Glucosinolates in Brassicales vegetables are of special interest due to their health-promoting properties in general and cancer preventive properties of their breakdown products in particular (Traka and Mithen, 2009; Veeranki et al., 2015). In plants, glucosinolates play a key role in the plant's defense system, and in case of injury to the plant cell, glucosinolates are enzymatically decomposed by the endogenous enzyme myrosinase and various degradation products, such as nitriles, epithionitriles, and/or isothiocyanates, are released (Hanschen et al., 2017). Of note is that isothiocyanates are associated with the pungency of these vegetables and have been shown to confer anti-cancerogenic (Abdull Razis and Noor, 2013; Avato and Argentieri, 2015; Dinkova-Kostova and Kostov, 2012; Hayes et al., 2008; Hecht, 2000; Higdon et al., 2007; Johnson, 2002; Kumar et al., 2015; Lippmann et al., 2014; Mithen, 2001; Traka and Mithen, 2009; Veeranki et al., 2015), anti-inflammatory (Bentley-Hewitt et al., 2014; Herz et al., 2016), as well as anti-diabetogenic (Guzmán-Pérez et al., 2016; Waterman et al., 2015) effects. In this regard, broccoli is the best studied species of *Brassica* vegetables to date (Jeffery and Araya, 2009; Moreno et al., 2006; Shapiro et al., 2001; Vasanthi et al., 2009).

Table 1
Names of glucosinolates.

Chemical name of	Trivial name
2-propenyl	sinigrin
3-butenyl	gluconapin
(*R*)-2-hydroxy-3-butenyl	progoitrin
4-pentenyl	glucobrassicanapin
4-mercaptobutyl	glucosativin
4-(methylthio)butyl	glucoerucin
4-(methylthio)3-butenyl	glucoraphasatin
3-(methylsulphinyl)propyl	glucoiberin
4-(methylsulphinyl)butyl	glucoraphanin
benzyl	glucotropaeolin
2-phenylethyl	gluconasturtiin
3-indolylmethyl	glucobrassicin
4-hydroxy-3-indolylmethyl	4-hydroxyglucobrassicin
4-methoxy-3-indolylmethyl	4-methoxyglucobrasicin
1-methoxy-3-indolylmethyl	neoglucobrassicin