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Effects of Storage Conditions on Furocoumarin Levels in Intact, Chopped, or Homogenized Parsnips

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Furocoumarins represent a family of natural food constituents with phototoxic and photomutagenic properties. They are found mainly in plants belonging to the Rutaceae and Umbilliferae such as celery, carrots, and parsnips. Parsnips (*Pastinaca sativa* L.) have become more and more popular as a vegetable, e.g., as a constituent of or ingredient in baby food. Previous work has shown that microbial infection of parsnip roots can result in a dramatic increase in furocoumarin levels. In this study, freshly harvested parsnips were stored as whole roots, pieces (cubes), or homogenate at +4 °C or −18 °C over various time periods under standard conditions. It was found that furocoumarin concentrations (sum of five furocoumarins: angelicin, isopimpinellin, 5-methoxypsoralen, 8-methoxypsoralen, and psoralen) in freshly harvested parsnips, analyzed by HPLC after extraction with diethyl ether and sequential solid phase (reversed-phase and silica) extraction, was generally lower than 2.5 mg/kg, and storage of parsnips in any form investigated at −18 °C over up to 50 days did not lead to a marked increase in furocoumarin levels. In contrast, storage of whole parsnips, but not of cubes or homogenate, at +4 °C resulted in a marked biphasic increase of furocoumarin concentrations after 7 and 38 days of storage up to levels of about 40 mg/kg. A dramatic increase in furocoumarin concentrations up to 566 mg/kg was observed when whole parsnips obtained from the market were kept at room temperature over 53 days, resulting in a visible microbial (mold) infection. Baby food products from the German market containing parsnips as an ingredient or constituent showed furocoumarin levels ≤0.41 mg/kg, suggesting that properly stored roots/preparations have been used. It is recommended that, after harvesting, parsnips be kept at −18 °C or under other conditions that prevent microbial infections.

KEYWORDS: Baby food; furocoumarins; food levels; microbial infections; parsnips; storage conditions

INTRODUCTION

Furocoumarins are present in many fruits and vegetables as natural constituents. Plants with relatively high natural furocoumarin levels are mainly found among Rutaceae and Umbelliferae (*1*, *2*). Furocoumarins are well-known to act as phototoxicants in combination with UVA irradiation (wavelength 320−380 nm) exhibiting cytotoxic and mutagenic properties (*3*−*5*). Possible mechanisms leading to adverse effects include binding to cellular constituents (*6*), lysosomal damage (*7*), generation of reactive oxygen species (*8*), and formation of novel antigens through covalent modification of proteins and DNA (*9*). Even in the absence of UVA light, daily doses of 200 and 400 mg 8-methoxypsoralen (MOP)/kg body weight (given orally over ninety days; 5 days a week) have been reported to exert toxic effects on liver, testes, and epididymis in rats (*10*). Furthermore, a number of furocoumarins act as inhibitors of drug metabolizing enzymes. 6′,7′-Dihydroxybergamottin and related furocoumarin dimers found, e.g., in grapefruit juice act as highly potent inhibitors of cytochrome P450 (CYP) 3A and other CYP isozymes (*11*) affecting drug metabolism.

Average daily furocoumarin intake via food was estimated as 1.3 mg per person in the U.S. (*2*), with lemon−lime flavored carbonated beverages being considered as a major source. Other sources include celery (*Apium graveolens* L.), parsley (*Petroselinum crispum*), parsnip, grapefruit (*Citrus paradisi*), lemon (*Citrus limon*), carrot (*Daucus carota* L.), and orange *(Citrus aurantium* L.). Ingestion of celery in combination with UVA irradiation has resulted in severe skin burn (*12*). In parsnips (*Pastinaca sativa* L.) furocoumarin levels vary enormously and have been reported to be enhanced upon infection with the fungus *Phoma complanata* (*13*). Values up to almost 2500 mg/kg were found in infected parsnips, whereas average levels

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between 20 mg/kg and 96 mg/kg were reported in roots from the market (*14*, *15*). Treatment with the fungicide chlorothalonil resulted in a slight increase in furocoumarin levels (*13*) attributed to "cell stress" elicited by the fungicide. Dramatic increases in furocoumarin levels upon microbial infection during storage (temperature of +4 °C; relative humidity of approximately 75%) were also reported to occur in celery (*16*).

Although the increase in furocoumarin levels in infected parsnips is regarded as a defense reaction of the plant, less is known about the general influence of processing such as homogenization or storage conditions on the furocoumarin levels in parsnips.

Because of their aromatic taste, parsnips have become more and more popular as a vegetable and, in particular, as a constituent of or ingredient in baby food. This fact led us to investigate how various storage conditions can influence furocoumarin levels in parsnips in whole roots, cubes, or homogenate.

MATERIALS AND METHODS

In the present study, freshly harvested parsnips were stored as intact roots, pieces (cubes), or homogenate at −18 °C or +4 °C and the furocoumarin level was analyzed at various points in time. For comparison, furocoumarins were analyzed in parsnips from the market stored as roots, pieces, and homogenate at room temperature or +4 °C allowing spontaneous microbial infection, as well as in baby food products from the German market containing parsnips as an ingredient or constituent, where low levels of furocoumarins were found.

8-Methoxypsoralen (MOP), 5-MOP, and psoralen were from Sigma-Aldrich (Deisenhofen, Germany), and angelicin and isopimpinellin were from Roth (Karlsruhe, Germany). All solvents and other chemicals used were of the highest purity commercially available for chromatographic analysis. As hydromatrix for solid-phase extraction calcined diastomaceous earth (Wetsupport; Isco, Inc., Lincoln, NE; CAS 91053-39-3) was used. Parsnips at a wet weigth of 0.5−1.5 kg per root were obtained in two batches at the days of harvest from a farm in the area of Karlsuhe (Germany). Celery roots and various types of ready-to-use sterile baby food were purchased in a supermarket. For the study of the effects of spontaneous infection, parsnips of unknown age were purchased from the market.

The parsnips were stored as whole roots, cubes (1-cm edge length), or homogenate over various time periods ≤ 48 days. Homogenates were prepared in a robot coupe R 301 ultra mixer. The preparations were stored at +4 ± 1 °C, −18 ± 1 °C, or room temperature (+22 ± 3 °C) in closed polyethylene cups or in cardbord boxes (whole parsnips).

Furocoumarins were analyzed according to Baumann et al. (*14*). Briefly, whole or chopped parsnips or baby food were homogenized, and about 5 g of the homogenate was mixed with 15 mL of water and 10 mL of diethyl ether. This mixture was then homogenized in an Ultra-Turrax homogenizer. After centrifugation at 10000×*g* over 10 min, the organic phase was collected. The extraction/centrifugation step was repeated twice, and the organic phases were combined. After evaporation of the solvent under reduced pressure, the dry residue was dissolved in 0.6 mL of acetonitrile. After addition of 0.4 mL of water, the mixture was applied to a reversed-phase (C_{18}) chromatography column. After elution with 60% acetonitrile in water, the solvents were removed from the eluate under reduced pressure. The dry residue was dissolved in chloroform and applied to a SiOH chromatography column. After elution with 7.5% ethyl acetate in chloroform, the solvents were removed from the eluate under reduced pressure. The dry residue was dissolved in 0.5 mL of methanol, and analyzed by HPLC on an LC 1090 chromatography system (Hewlett-Packard, Waldbronn, Germany) equipped with a 1090 UV diode array detector set at $\lambda = 304$, 270, and 246 nm, and a Superspher RP 18 column (200 × 2.1 mm; 4 μm). A water/methanol mixture (45:55, v/v) was used as the mobile phase at 40 °C and a flow rate of 0.2 mL/min.

The furocoumarins were identified on the basis of their retention time and characteristic UV spectrum. The concentrations were calculated from calibration curves with pure reference compounds using the peak height as parameter. Recovery rates (means and standard deviations from experiments carried out in triplicate at two levels each) of 93.2 ± 1.2% for 8-MOP, 84.9 ± 1.8% for psoralen, 72.0 ± 1.1% for angelicin, 94.4 ± 0.9% for isopimpinellin, and 91.5 ± 0.6% for 5-MOP were found after addition of pure reference compounds to homogenized celery, and were considered when the concentrations in parsnips were calculated. The detection limit was about 0.5 μg/mL.

Analyses were carried out in three different samples from the same batch of parsnips (stored as whole roots, cubes, or homogenate). The reported data represent arithmetic means ± standard deviation. For statistical comparison with the samples from freshly harvested parsnips, Dunnett's test for multiple comparison with a control was used. In moldy parsnips and in baby food products two analyses were carried out from each sample. The reported data shown in the tables represent means from two analyses.

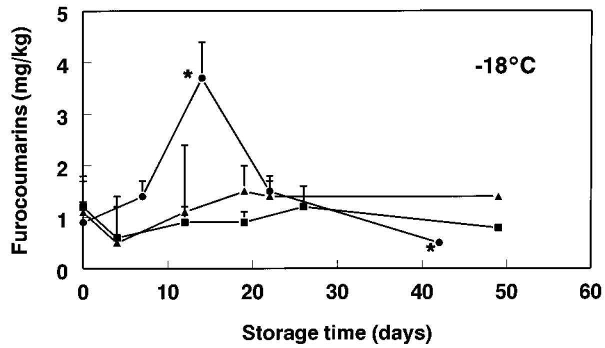

Figure 1. Furocoumarins (sum of angelicin, isopimpinellin, 5-MOP, 8-MOP, and psoralen) in whole roots (-●-), cubes (-+-), or homogenized parsnips (-▲-) stored at −18 °C for the time periods indicated. Points represent means ± SD from three parallel experiments (same batch of freshly harvested parsnips). *Significantly ($p \leq 0.05$) different from control (timepoint zero).

RESULTS

In the first part of this study, freshly harvested parsnips were used. The total furocoumarin levels (sum of five furocoumarins: angelicin, isopimpinellin, 5-MOP, 8-MOP, and psoralen) in freshly harvested parsnips were in the range of 1 mg/kg wet weight (**Figure 1**). Slight differences between the levels in whole roots, pieces (cubes), and homogenate at time point zero were due to the fact that different roots were used for each preparation. Parsnips were stored either as whole roots, cubes, or homogenate over a period of ≤50 days at +4 °C or −18 °C under standardized conditions. It was found that storage of cubes or homogenate at −18 °C resulted in furocoumarin levels below 2.5 mg/kg (**Figure 1**). Storage of whole roots at −18 °C led to a peak level of total furocoumarins of about 4 mg/kg two weeks after harvesting. The levels decreased thereafter, at 22 and 42 days, to the same range as that in homogenates or cubes (**Figure 1**). The rise of furocoumarin levels in whole parsnips after two weeks of storage at −18 °C was due to an increase in the levels of all furocoumarins with the exception of psoralen which was markedly decreased in comparison to that of freshly harvested roots (**Figure 2a−e**). 5-MOP already exhibited a marked increase after 7 days.

In contrast to freezing conditions, storage of whole parsnips at +4 °C led to a marked increase in furocoumarin concentrations after 7 days, achieving an average level of 33 mg/kg total furocoumarins (**Figure 3**). After 40 days of storage, the total amount of furocoumarins as well as the levels of all individual furocoumarins (**Figure 4**), raised significantly in whole roots. This increase was accompanied by the occurrence of molds on the surfaces of the roots. In cubes, but not in homogenate, a

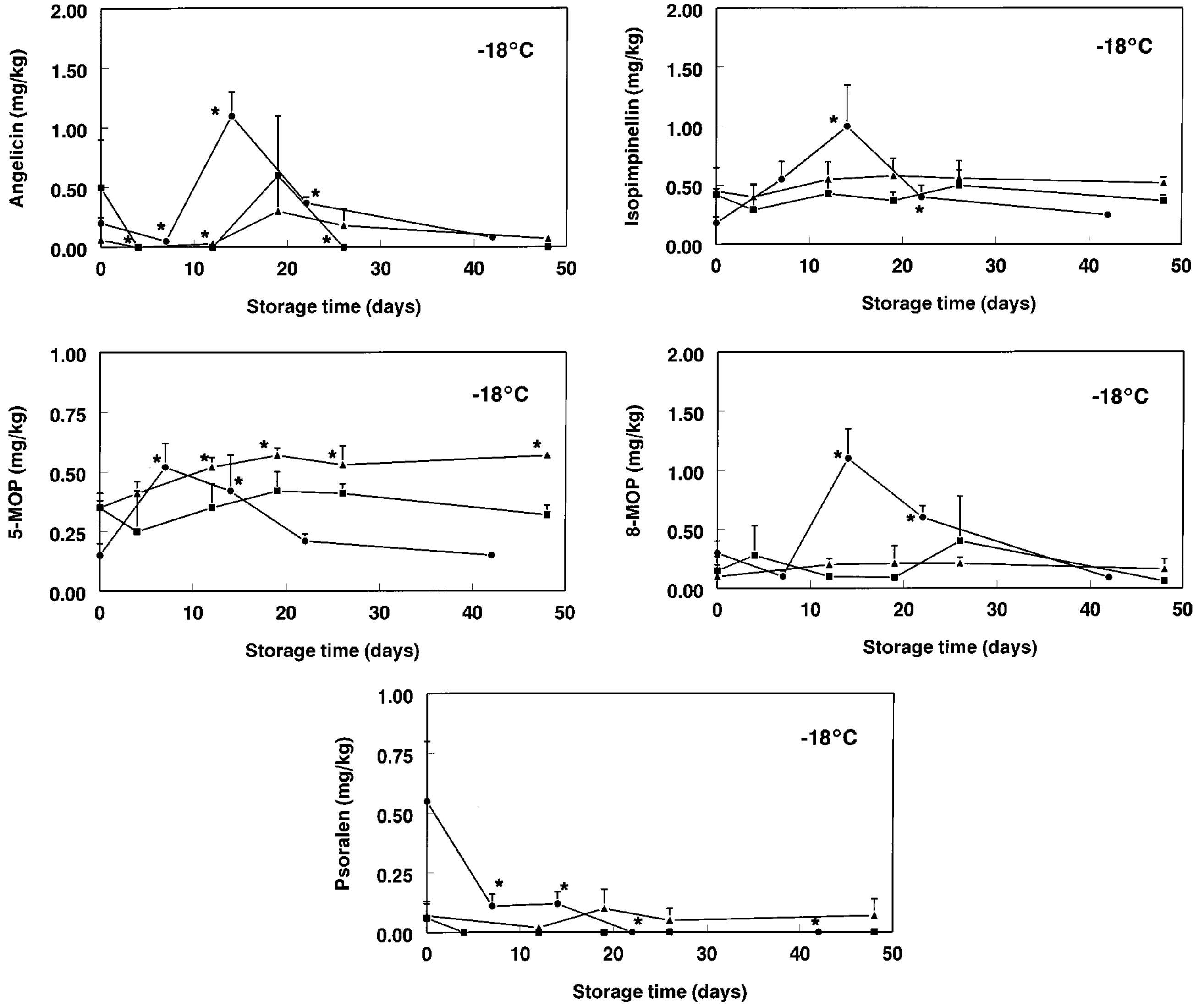

Figure 2. Levels of individual furocoumarins (angelicin (a), isopimpinellin (b), 5-MOP (c), 8-MOP (d), or psoralen (e), as indicated) in whole roots (-●-), cubes (-+-), or homogenized parsnips (-▲-) stored at –18 °C for the time periods indicated. Points represent means ± SD from three parallel experiments (same batch of freshly harvested parsnips). *Significantly ($p \leq 0.05$) different from control (timepoint zero).

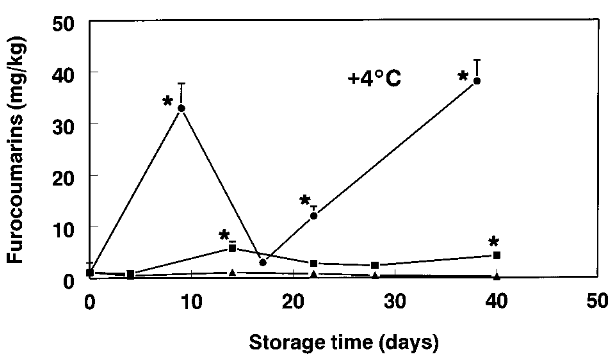

Figure 3. Furocoumarins (sum of angelicin, isopimpinellin, 5-MOP, 8-MOP, and psoralen) in whole roots (-●-), cubes (-+-), or homogenized parsnips (-▲-) stored at +4 °C for the time periods indicated. Points represent means ± SD from three parallel experiments (same batch of freshly harvested parsnips). *Significantly ($p \leq 0.05$) different from control (timepoint zero).

slight increase was observed upon storage over 14 days; with the levels being in the range of ≤6 mg/kg.

In parsnips purchased from the market (storage time not known) levels of up to 49 mg/kg were found, with angelicin and 8-MOP being the predominant furocoumarins (data not shown). When these parsnips were stored over an additional 53 days at room temperature or +4 °C as roots, cubes, or homogenate, massive infection with bacteria and molds occurred. The furocoumarin concentrations reached very high levels in moldy roots or cubes but not in the homogenates (**Table 1**). This was due to an over-proportional increase in angelicin and 8-MOP compared to their patterns in freshly harvested roots.

In baby food products from the German market (**Table 2**) containing parsnips as a constituent or ingredient, furocoumarin levels were in the range of 0.06−0.41 mg/kg. It was found that a product with a presumably higher parsnip content showed the highest levels of furocoumarins.

DISCUSSION

In freshly harvested parsnips a total furocoumarin level in the range of 1 mg/kg was found, which is slightly lower than that reported by Mongeau et al. (*13*). Parsnips purchased from the market, however, contained levels up to 49 mg/kg which is in the same range as those found by others (*2*, *14*, *16*). During storage of freshly harvested parsnips at −18 °C minor increases in furocoumarin levels reaching about 4 mg/kg were found. The

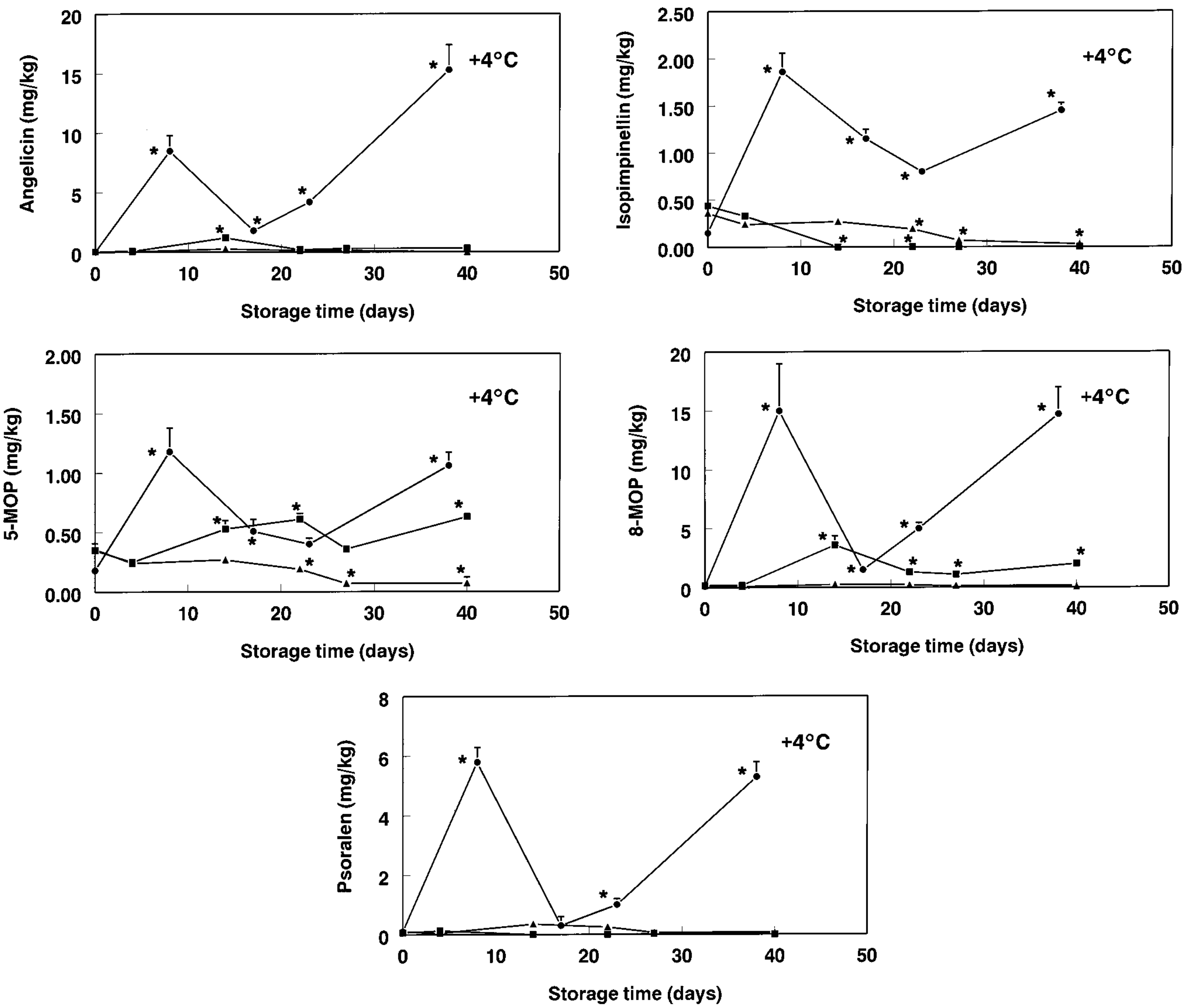

Figure 4. Levels of individual furocoumarins (angelicin (a), isopimpinellin (b), 5-MOP (c), 8-MOP (d), or psoralen (e), as indicated) in whole roots (-●-), cubes (-+-), or homogenized parsnips (-▲-) stored at +4 °C for the time periods indicated. Points represent means ± SD from three parallel experiments (same batch of freshly harvested parsnips). *Significantly ($p \leq 0.05$) different from control (timepoint zero).

Table 1. Furocoumarin Levels (mg/kg) in Moldy Whole Parsnips, Cubes, and Homogenate after 53 Days of Storage[a]

furocoumarin	whole roots (+4 °C)	cubes (+22 °C)	homogenate (+4 °C)
angelicin	205.9	169.4	0.3
isopimpinellin	14.5	53.7	n.d.
5-MOP	14.8	49.4	0.1
8-MOP	248.6	241.0	n.d.
psoralen	36.7	53.1	n.d.
total	520.5	566.5	0.4

*Means of results of two analyses from one sample each; n.d. = not detectable.

Table 2. Furocoumarin Levels (Sum of Angelicin, Isopimpinellin, 5-MOP, 8-MOP, and Psoralen) in Baby Food Products from the German Market[a]

product declaration	probable content of parsnips (estimate)	furocoumarins (mg/kg)
vegetables with millet	ingredient	0.06
vegetables with noodles	ingredient	0.12
root vegetables	constituent	0.21
parsnips	major constituent	0.41
mixed vegetables	constituent	0.05
vegetable pasta	ingredient	0.06

[a] Means of results of two analyses from one sample each.

five furocoumarins analyzed contributed to this peak to different degrees: i.e., 5-MOP was at a maximum level already after 7 days, while psoralen decreased over the whole period of storage. These findings are in agreement with the assumption that psoralen is a precursor of 5-MOP, 8-MOP, and isopimpinellin (*18*). The biosynthesis of angelicin proceeds via other intermediates, and is independent of this pathway (*19*). This fact is consistent with the finding that angelicin was the only furocoumarin investigated showing a marked transient increase during storage of cubes at −18 °C.

Storage of roots at +4 °C resulted in a biphasic rise of furocoumarins. After 7 days the first peak reaching levels of about 30 mg/kg was observed for all furocoumarins analyzed, suggesting that the response was operative prior to the level of psoralen and/or the precursor(s) of angelicin. It is unclear if this effect resulted from a “stress response” related to the harvest or storage or from a subtle microbial infection. However, the fact that this type of response was observed at −18 °C in a delayed and attenuated manner, suggests that it can be at least partially attributed to harvest/storage stress. Thereafter, the levels declined suggesting a degradation of furocoumarins. After 38 days the levels of the five furocoumarins were markedly increased again. This second rise was possibly related to a beginning microbial infection, although no massive infections were visible macroscopically.

The rise in furocoumarins in whole roots stored at +4 °C was mainly due an increase in angelicin, 8-MOP, and psoralen, while isopimpinellin and 5-MOP were minor contributors.

Interestingly, storage of cubes at +4 °C led to a markedly attenuated response both at 7 and 38 days. In homogenate, almost no rise in furocoumarins was observable.

There are several possible explanations for this finding. One possibility is that the skin of parsnips may represent a major site of furocoumarin biosynthesis. However, in our experiments, skin tissue was not removed prior to cutting or homogenization. Therefore, alterations in biosynthsis and/or degradation of furocoumarins in the presence of the higher oxygen concentrations prevailing in chopped or homogenized parsnips may explain our findings. However, furocoumarins have not been reported to be sensitive toward oxygen per se. Likewise, furocoumarin crystals were reported to deposit on the surface of parsnips (*19*). It appears likely that oxidases not present at the surface but in the tissue can degradate furocoumarins if oxygen is present in abundance. Another possibility is that the biosynthesis of furocoumarins is disturbed by high oxygen levels. Alternatively, the homogenization may give access to enzymes that modify furocoumarin levels without oxygen being involved. This explanation, however, is less convincing because cubes with most of the tissue left intact also showed markedly reduced levels.

In agreement with previous reports (*13*, *20*), storage of parsnips from the market (unknown length of pre-storage) under conditions allowing mold and bacterial infections resulted in a massive rise in furocoumarins. This effect was also prominent in cubes. In moldy parsnip homogenates, however, this effect was absent, suggesting an influence of tissue destruction and/or the enhanced access of oxygen. It is unknown whether massive mold infection can overcome those modifying influences that prevent, e.g., a marked rise in cubes not bearing visible infections. The pattern of individual furocoumarins in massively infected roots and cubes was predominated by angelicin and 8-MOP. This finding suggests that the biosynthesis of both angular and linear furocoumarins has been turned on.

The massive increase of furocoumarins in moldy roots is of particular importance because it indicates the need for controlled storage of roots used for manufactured products.

In baby food products from the German market furocoumarin levels were low. As the exact percentage of parsnips in those products is unknown, however, the furocoumarin levels in the parsnips used cannot be estimated. Assuming that parsnips were added to the product in a range between 5 and 50%, it is likely that no material from massively infected roots had been used. Under usual dietary habits, the levels in those market products do not lead to furocoumarin doses high enough to reach a critical concentration of furocoumarins in blood as identified by Schlatter et al. (*21*). In volunteers, the oral intake of 50 mg of 8-MOP resulted in erythema and edema upon exposure to sunlight (*22*). In a study by Brickl et al. (*23*), a threshold dose of 14 mg (0.24 mg/kg body weight) of 8-MOP was found to cause erythema in humans.

In conclusion, our findings demonstrate that furocoumarin levels in parsnips are maintained at a very low level when storage is performed at −18 °C. At +4 °C, whole parsnips show a biphasic increase in furocoumarins which was much lower in cubes and almost absent in homogenate. Whole roots or cubes, but not homogenates, with massive microbial infections contained high levels of furocoumarins. In baby food products from the German market containing parsnips as a constituent or ingredient, relatively low furocoumarin levels were found.

It is suggested that parsnips should be stored at −18 °C or under other conditions that prevent microbial infection. In parsnips stored at higher temperatures furocoumarin levels can be high even when no massive microbial infection is visible. Further work is necessary to investigate the basis for the low furocoumarin levels found in homogenized parsnips.

ABBREVIATIONS USED

CYP, cytochrome P450; 5-MOP, 5-methoxypsoralen; 8-MOP, 8-methoxypsoralen; UVA, ultraviolet light A.

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