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WASTE PRODUCTS FROM FRUIT AND VEGETABLE PROCESSING AS POTENTIAL SOURCES FOR FOOD ENRICHMENT IN DIETARY FIBRE

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Abstract. The objective of our study was to determine and compare the neutral dietary fibre (NDF) and acid dietary fibre (ADF) contents in the pomace from the processing of two apple varieties (Idared and Champion), two strawberry varieties (Ducat and Kent), chokeberry, black currant, red cabbage, and two carrot varieties (Black carrot and Dolanka). Chokeberry pomace was found to contain the largest, and Dolanka carrot pomace the smallest amounts of NDF and ADF. The results imply that chokeberry pomace, black currant pomace and strawberry (both Ducat and Kent) pomace should be recommended as best suited for the production of high DF food components.

Key words: pomace, dietary fibre fractions

INTRODUCTION

Although its health-promoting properties have been recognized for several decades, the dietary fibre itself has long been regarded as an indigestible ballast component of a food plant. Since the mid-1960s the interest in the nutritional implications of dietary fibre has continued to grow. Most of the research has concentrated on the physiological properties of dietary fibres and how they influence the gastrointestinal tract. Many of those studies have revealed that the components of dietary fibre show the ability to bind a number of substances, including cholesterol and gastric juice [Jenkins et al. 1998, Jiménez-Escrig and Sánchez-Muniz 2000]. Some of the investigators have demonstrated that, owing to its properties, dietary fibre plays an important role in the prevention and cure of diabetes, obesity, atherosclerosis, heart diseases, colon cancer and colorectal cancer [Wang et al. 2002, Ferguson and Harris 2003, Ferguson 2005]. Hemicellulose and pectin were found to have a remarkable capability of binding metal ions. The same proved to be true for cellulose and lignin, though to a smaller extent, because the source of origin notably affects the metal binding properties of the two fractions [Nawirska

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2005]. Analysis of epidemiological data has revealed a causal link between civilization diseases and diets poor in dietary fibre. In developed countries, the low DF content in human diet is blamed for the development not only of civilization diseases (atherosclerosis, obesity, diabetes, tooth decay) but also of non-infectious diseases of the gastrointestinal tract (chronic constipation, appendicitis, polyps, tumors) [Jiménez-Escrig and Sánchez-Muniz 2000, Sangnark and Noomhorm 2003, Mai et al. 2003, Corréa Lima and Gomes-da-Silva 2005, Rodrígez et al. 2006].

The term 'dietary fibre' is generally understood to mean vegetable polysaccharides and lignins that retain their resistance when exposed to the influence of digestive enzymes in the human gastrointestinal tract [AACC... 2001]. Dietary fibre consists of constructive substances (such as cellulose, hemicellulose, lignins and pectins), resins and waxes [Prosky 1999].

As its chemical structure differs from one fraction to another, the nutritional implications of dietary fibre differ in the same way. Soluble DF fractions (pectin, gum, some of the hemicelluloses) undergo bacterial fermentation in the gastrointestinal tract and influence the metabolism of carbohydrates and fats. Insoluble DF fractions (cellulose, lignin, hemicellulose) shorten the gastrointestinal transit time and thus prevent constipation; they exert an inhibiting effect on the development of many rectal cancer forms by favourably stimulating the growth of intestinal microflora and preventing that of putrefactive bacteria [Bingham et al. 2003].

The foregoing account of literature supporting the role of DF in preventing civilization diseases need not be pursued further. Suffice it to point out the neccessity of finding as many potential DF sources for food enrichment as possible. Apart from the continuing rise in the consumption of foods rich in dietary fibre, there is also a growing demand for DF-enriched products, as well as for preparations and parapharmaceuticals being concentrated DF sources. Products enriched with DF might be available in a variety of forms, whereas the DF itself might differ in composition, origin and quantity from one product to another. The preparations could include either all of the DF fractions contained in the food plant of choice or isolated single fractions (e.g., preparations of pure cellulose, plant gum or pectins, etc.).

To produce DF-enriched preparations, use is made primarily of those parts of cereals, fruit and vegetables that are rich in non-digestible carbohydrates. The starting materials for the production of DF preparations are bran, straw, corn cobs and chaff, as well as the by-products or wastes from industrial processing of fruit and vegetables, i.e. apple, currant, citrus fruit, carrot, tomato, melon or spinach pomace. Their utilization is convenient and cost-effective and, what is more, enables rational management of troublesome wastes.

Many investigations have been reported concerning the health benefits or the quantities of the dietary fibre found in fruit, vegetables and cereals [Jenkins et al. 1998, Jiménez-Escrig and Sánchez-Muniz 2000, Wang et al. 2002, Ferguson and Harris 2003]. The literature also contains references to the variations of the DF content in food which was made subject to thermal processing [Rahman et al. 2002, Almada Costa and Silva Queiroz-Monici 2006]. Furthermore, reports are published on some new applications of fibres in foods [Borderías et al. 2005]. However, not very exhaustive information has been conveyed in the literature about pomace as a waste product from industrial processing of fruit and vegetables that can be utilized as a cost-effective and valuable source for food enrichment.

The aim of our present study was to determine and compare the contents of neutral and acidic DF fractions, as well as fractions of cellulose, hemicellulose and lignins, in the pomace of selected fruits and vegetables. In addition, the contents of the investigated fractions were compared in two varieties of carrot, apple and strawberry. The results may be of support when selecting suitable pomace for the preparation of specific high-DF composites, or when the pomace is to be used as an additive to some products.

MATERIALS AND METHODS

Samples

The pomace samples under study were prepared from the residues obtained after pressing vegetables (orange carrots, black carrots and red cabbage) or fruits (apples: ‘Champion’ and ‘Idared’; strawberries: ‘Ducat’ and ‘Kent’; black currants and chokeberries) for juice extraction. Black currant pomace was obtained from the Fruit and Vegetables Processing Plant Gomar, Pinczow/Poland. The other pomace samples came from fruit and vegetables pressing carried out at the laboratory of the Department of Fruit, Vegetables and Cereals Technology, Wroclaw University of Environmental and Life Sciences

Fibre analysis

The study reported on in this paper was carried out at the laboratory of the Department of Fruit, Vegetables and Cereals Technology, Wroclaw University of Environmental and Life Sciences. Immediately upon arrival in a wet state at our laboratory, the material was frozen. Prior to physical and chemical determinations, it was defrosted, dried and ground. The samples prepared via the above route were analyzed for dry matter content (by the AOAC method), the soluble and insoluble DF fractions being separated by the van Soest procedure, using an acidic or inert detergent. In this method DF fractions are separated (under defined conditions) from the other pomace components via treatment with surface-active compounds [Soest et al. 1991]. Cellulose content was determined by etching the sample with a mixture of nitric, acetic and trichloroacetic acids. The proportion of hemicellulose was calculated from the difference between NDF and ADF and that of lignin from the difference between ADF and cellulose. The results reported in the literature have made it clear that the amount of DF depends on the method with which it was determined. And this necessitates a detailed description of the methods used in order to enable comparisons of the results obtained in our study with those published elsewhere.

Statistical analysis

Each sample was analyzed in triplicate and the data were then averaged. Analysis of variance was used for data assessment. Means were calculated using the Duncana multiple range test, the significance level being $\alpha \leq 0.05$.

DISCUSSION OF RESULTS

Even though the available literature includes many references to DF and DF-related problems, little information has been reported on the DF content in the pomace obtained from the processing of particular fruit or vegetable by-products, which can be used for the production of high-cellulose preparations [Borycka and Górecka 2001]. Our investigations into fruit and vegetable pomace have revealed an NDF content of 18 to 87% DM, and an ADF content ranging between 16 and 57% DM.

Table 1. Proportion of NDF, ADF, cellulose, hemicellulose and lignin in pomace, g/100 g DM
Tabela 1. Zawartość NDF, ADF, celulozy, hemicelulozy i lignin w wytłokach, g/100 g s.m.

Pomace Wytłoki	NDF	ADF	Cellulose Celuloza	Hemicellulose Hemiceluloza	Lignin Lignina
'Idared' apple Jabłka 'Idared'	24.20^{h} ±0.54	19.81^{f} ±1.74	3.64^{g} ±1.24	4.26^{d} ±1.45	6.17^{f} ±1.32
'Champion' apple Jabłka 'Szampion'	31.27^{f} ±0.28	$21.90^{e,f}$ ±1.43	16.10^{e} ±0.90	9.37^{c} ±1.19	$5.80^{f,g}$ ±0.98
'Ducat' strawberry Truskawki 'Ducat'	55.19^{d} ±0.37	45.05^{c} ±1.38	29.35^{b} ±1.02	10.13^{c} ±1.07	$15.70^{d,e}$ ±0.83
'Kent' strawberry Truskawki 'Kent'	58.25^{c} ±0.67	46.70^{c} ±0.64	25.86^{c} ±0.78	1.55^{e} ±0.21	20.84^{c} ±0.15
Chokeberry Aronia	87.48^{a} ±0.60	57.24^{a} ±2.05	34.56^{a} ±1.26	30.24^{a} ±0.82	22.68^{b} ±0.25
Black currant Czarna porzeczka	63.55^{b} ±0.66	47.67^{b} ±0.94	21.01^{d} ±0.88	15.87^{b} ±0.32	26.66^{a} ±0.11
'Black' carrot Marchew 'Czarna'	28.55^{g} ±0.62	23.57^{e} ±0.52	16.28^{e} ±0.91	4.98^{d} ±0.12	7.29^{f} ±1.06
'Dolanka' carrot Marchew 'Dolanka'	18.05^{i} ±0.69	16.02^{g} ±0.75	12.65^{f} ±0.91	2.03^{e} ±0.22	3.37^{h} ±0.86
Red cabbage Czerwona kapusta	34.76^{e} ±0.87	29.33^{d} ±1.04	15.21^{e} ±0.89	5.43^{d} ±0.27	14.12^{e} ±0.65

*Mean of three replications; if different within a column, indicates significant difference ($\alpha \le 0.05$).
*Średnia z trzech powtórzeń; różnice w kolumnach oznaczone różnymi indeksami różnią się istotnie między sobą ($\alpha \le 0,05$).

The comparison of the NDF and ADF values for fruit pomace and vegetable pomace summarized in Table 1 makes it clear that the DF content is high in both the pomace types. The NDF contained in the fruit pomace varies from 24.20 g/100 g DM to 87.48 g/100 g DM, and that in the vegetable pomace from 18.05 g/100 g DM to 34.76 g/100 g DM (Table 1). The differences in the NDF content are statistically significant, and neither of the two pomace types has formed homogeneous groups. The ADF content is very high in the fruit pomace (19.81 to 57.24 g/100 g DM) and slightly lower in the vegetable pomace (16.02 g/100 g DM to 29.33 g/100 g DM). Statistical analysis of the ADF content has revealed seven homogeneous groups. The pomace from chokeberry, red cabbage and 'Dolanka' carrot pressing has formed independent homogeneous groups. Black currant pomace and 'Kent' strawberry pomace belong to the same single group. The pomace from both types of strawberries and that from both types of apples have formed two separate groups; the last of the homogeneous groups being made of 'Black' carrot and 'Champion' apples.

Of the pomace samples examined, those of chokeberry pomace are the richest in dietary fibre, containing the highest amounts of NDF (87.49 g/100 g DM) and ADF (57.24 g/100 g DM). They also show the highest content of cellulose (34.56 g/100 g DM) and hemicellulose (30.24 g/100 g DM). A previous study, where use was made of another method for the determination of DF fractions [Nawirska and Kwaśniewska 2005] has produced similar findings: cellulose and hemicellulose amounted to 34.56 g/100 g DM and 30.24 g/100 g DM, respectively.

Black currant pomace ranked second in terms of DF content, with NDF of 47.67 g/100 g DM, ADF of 63.55 g/100 g DM, cellulose of 15.88 g/100 g DM, hemicellulose of 21.01 g/100 g DM, and lignin of 26.66 g/100 g DM (the latter occurring in a greater amount than that in the chokeberry pomace samples). These results (twice as high) are inconsistent with those obtained previously [Nawirska and Kwaśniewska 2005].

Insignificant differences in the proportions of particular fractions were detected in the pomace of both 'Kent' and 'Ducat' strawberries. Statistical analysis, however, has revealed significant differences between the two strawberry varieties; it was only in the case of the ADF content that the two varieties constituted a homogeneous group. The 'Kent' strawberry pomace contained slightly greater amounts of all DF components, but was noticeably richer in lignin ('Kent' – 20.84 g/100 g DM; 'Ducat' – 15.70 g/100 g DM).

Of the fruit pomace samples examined, those of the apple pomace were found to contain the lowest DF amounts, but with the 'Champion' apple, the DF content was higher (Table 1). These values are slightly lower than those reported by Dolreans et al. [1995] NDF 43.22% DM at apple pomace. Figuerola et al. [2005] have confirmed the occurrence of differences in the TDF contained in apple pomace, which were due to the type of the apple used (from 60.7 to 89.8 g/100 g DM). Similar results have been reported by Grigelmo-Miguel and Martín-Belloso [1999] (TDF, 60.1 g/100 g DM lignin, 12.5 g/100 g DM). As for cellulose, hemicellulose and lignin, their content was much higher in the previous [Nawirska and Kwaśniewska 2005] than in the present study. It should, however, be noted that in the previous study the pomace samples under analysis came from the Fruit Processing Plant of Prusice (Poland). There was no selection according to apple variety, and the pomace was exposed to strong enzyme preparations.

As it may be inferred from the analysis of statistical data in our present study, both the apple varieties formed homogeneous groups for ADF and lignin fractions. Other analyses have revealed differences of statistical significance. The apple pomace samples examined in our present study were characterized by a large amount of soluble DF fractions (as shown in the bar chart). Similar results have been obtained by Figuerola et al. [2005]. In their study, the soluble DF fraction (SDF) varied from 56.5 to 81.6 g/g DM, depending on the apple variety. Slightly lower amounts of SDF have been detected by Grigelmo-Miguel and Martín-Belloso [1999] in their pomace samples (46.3 g/100 g DM). This implies that the pomace contained large amounts of pectins which were not made subject to analysis in the present study.

Compared to the majority of fruit pomace samples, the vegetable pomace samples analyzed in our study showed slightly lower contents of particular DF fractions. The DF content was higher in the red cabbage pomace samples than in the pomace samples of 'Black' and 'Dolanka' carrots (NDF: 34.76 g/100 g DM; ADF: 29.33 g/100 g DM); cellulose and hemicellulose content amounting to 15.20 g/100 g DM and 14.13 g/100 g

DM, respectively. In the available literature no references were found to the DF content in red cabbage pomace samples or fresh red cabbage, although there is information on the DF content in white cabbage (NDF: 14.8 g/kg fresh mass; ADF: 11.6 g/kg fresh mass) [Rahman et al. 2002].

Of all the vegetable pomace samples studied, those of the carrot pomace (both 'Black' and 'Dolanka' carrots) showed the lowest DF content. Their characteristic feature was a very low amount of hemicellulose (2.03 and 4.98 g/100 g DM), similar amounts being determined in the 'Idared' apple pomace (4.26 g/100 g DM). This was not so in our previous study [Nawirska and Kwaśniewska 2005], where the content of lignins amounted to 32.2 g/100 g DM. As was the case with the apple pomace, a plausible explanation as to why these values are low in the present study can be drawn from the fact that the pomace under analysis came from industrial-scale processing of fruit and vegetables (with no selection of particular varieties), where use was made of enzymatic methods. The carrot pomace used in our study in 2005 was supplied by the Fruit and Vegetables Processing Plant Agros-Fortuna, Łowicz (Poland). These great differences may be due not only to the method of analysis applied but also to the fruit or vegetable variety used, to say nothing of the pressing process and the enzymes involved. From the data reported in the literature it is obvious that chemical composition depends on the fruit or vegetable variety used, and the same may hold true for the DF content. The NDF and ADF content in fresh carrot reported by Rahman et al. [2002] amounts to 13.5 and 11.6 g/kg fresh mass, respectively, and may be regarded as sufficiently correlated with the results obtained in the study reported on in this paper.

With a generally low amount of DF in 'Black' and 'Dolanka' carrots, the content of particular DF fractions was found to be significantly higher in the 'Black' carrot pomace. 'Black' carrot (as well as 'Black' carrot pomace) is rich in anthocyanins and should therefore be recommended as a valuable raw material for functional food production, in spite of the rather low DF content. As shown by the bars in Figure 1, the proportion of soluble fractions (pectins, gum, etc.) varies from one pomace sample

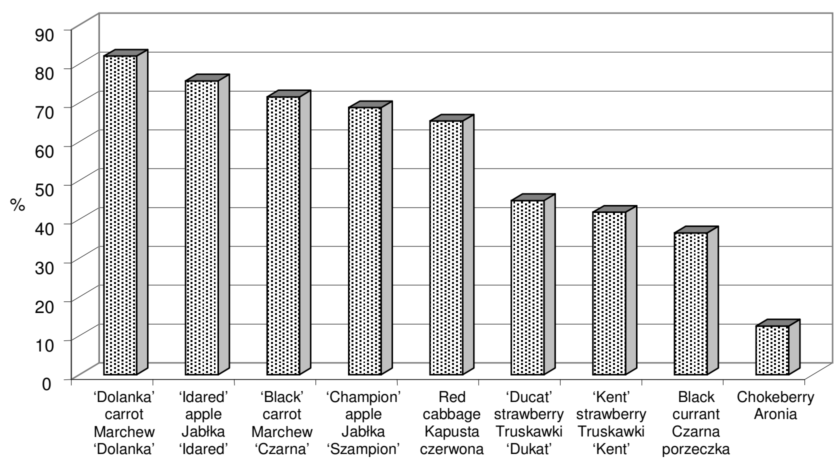

Fig. 1. Percentage of soluble fractions in pomace (S_r = 100 – NDF)
Rys. 1. Zawartość frakcji rozpuszczalnej w badanych wytłokach wyliczonych jako S_r = 100 – NDF

to another (12 to 82%). In the 'Dolanka' carrot, 'Idared' apple and 'Black' carrot pomace samples soluble DF fractions accounted for over 70% of the total volume. Slightly lower proportions have been detected in 'Champion' apple and 'Red' cabbage pomace. This is indicative of a low IDF fraction content (less than 40%). The lowest amount of the soluble DF fraction has been found in chokeberry pomace (about 12% only). Considering the high anthocyanin content, as well as the very low percentage of the soluble fraction, chokeberry pomace is a valuable source for the enrichment of functional food.

CONCLUSIONS

1. Examinated pomace was characterized by a different levels of dietary fibre fractions (NDF, ADF, cellulose, hemicelulose and lignins).
2. The highest level of dietary fibre characterized the pomace obtained from berry fruits.
3. Chokeberry pomace and 'Dolanka' carrot pomace were found to have the highest and the lowest proportion of dietary fibre fractions, respectively.
4. Pomace from chokeberry, black currant and strawberries can be used to industrial production of DF-rich concentrates.

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WYTŁOKI Z OWOCÓW I WARZYW JAKO POTENCJALNE SUROWCE DO WZBOGACANIA ŻYWNOŚCI WE WŁÓKNO POKARMOWE

Streszczenie. Włókno pokarmowe przez wiele lat było niedocenianym składnikiem żywność pochodzenia roślinnego. Obecnie docenia się jego właściwości i prozdrowotne oddziaływanie na przewód pokarmowy i cały organizm. Najnowsze badania dietetyczne potwierdzają konieczność spożywania odpowiednich jego ilości. Z tego względu poszukuje się surowców i produktów o jak największej zawartości DF. Takim surowcem, równocześnie będącym odpadem, są wytłoki z owoców i warzyw. Celem pracy było porównanie zawartości NDF i ADF w wytłokach z jabłek (odmiany 'Idared' i 'Szampion'), truskawek (odmiany 'Dukat' i 'Kent'), aroni, czarnej porzeczki, czerwonej kapusty oraz dwóch odmian marchwi – 'Czarnej' i 'Dolanka'. Po uzyskaniu wyników badań okazało się, że największe ilości obu frakcji oznaczono w wytłokach z aroni (NDF – 87,48 g/100 g DM, ADF – 57,24 g/100 g DM), a najmniejsze w wytłokach z marchwi 'Dolanka'. Do produkcji wysokobłonnikowych preparatów należy przeznaczyć wytłoki z aroni, porzeczek i obu odmian truskawek.

Słowa kluczowe: wytłoki, frakcje włókna pokarmowego (NDF, ADF)

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