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# Antioxidant properties of lupin seed products

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**Abstract**

Antioxidant properties of lupin flours and hulls were examined. Chemical composition (protein, fat, fatty acids, tocopherols and tannin contents) was determined and radiation effects were estimated (1, 5 and 10 kGy). Antioxidant properties of the ethanol lupin extracts were examined using the Rancimat and Oxidograph tests. Alpha-, gamma- and delta-tocopherols were found in the lupin oil. Lupin tannins contents in the flours were a few times higher than in the hulls. Antioxidant activity was found both in the flours and in the hulls. Correlation between the antioxidant properties and the tocopherol and tannin contents (the natural lupin antioxidants) was not found. Increasing doses of irradiation lowered antioxidant effects of lupin extracts; however, the antioxidant activities of some samples were higher. The observed negative changes in the tocopherols contents were effects of the irradiation dose as well as storage time.


*Keywords:* Lupin; Tocopherols; Tannins; Antioxidant activity; Irradiation

## 1. Introduction

World Health Organization studies have shown that the state of human health depends largely on nutrition. On the other hand, in human diseases, oxidative stress plays a role. The words "free radicals" and "antioxidants" have become well known for the health-conscious consumer. Lipid peroxidation is a major factor in deterioration during storage and food processing (Lambelet, Ducret, Saucy, Savoy, & Löliger, 1987; Löliger, Lambelet, Aeschbach, & Prior, 1996). It is also thought to induce physiological obstruction, causing aging of the cell and carcinogenesis. The roles of active oxygen and free radicals in tissue damage, in different diseases of humans, are becoming increasingly recognized (Halliwell, Gutteridge, & Cross, 1992). Active oxygen, in the form of superoxide, hydrogen peroxide and hydroxyl radicals, is a by-product of normal metabolism and attacks biological molecules, leading to cell or tissue injury. Active oxygen and free radicals are produced by certain chemical carcinogens and play a role in the carcinogenic process (Albanes et al., 1995; Johnson, 2001).

Now, the addition of an antioxidant is popular and applied as a means of increasing the storage period of food products and for improving the stability of lipids and lipid-containing foods without loss of sensory and nutritional qualities. It is a generally accepted technological procedure, but these days consumers, assuming that natural compounds are safer, prefer natural antioxidants to the synthetic ones. Until now, much research has been conducted to find natural antioxidants with high antioxidant activity.

Tocopherols are one of the best examined and most popular plant antioxidants in the food industry. The natural oxidation inhibitors, four tocopherol homologues, alpha-, beta-, gamma- and delta-, are native compounds present in the green parts of plants and in their seeds (Sheppard, Pennington, & Weihrauch, 1993). Each of them has different biological and antioxidant activities (Kamal-Eldin & Appelqvist, 1996). Tocopherols, being hydrophobic compounds, play an important role in protection against free radicals which are pro-

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duced in the oxidation processes (Halliwell, 1996). They act as the main antioxidants in cell membranes (Bramley et al., 2000).

Plant polyphenols can protect foodstuffs which easily undergo oxidation. For instance, they limit the oxidation of vitamin C, carotene, and unsaturated fatty acids. Biological activity of polyphenols is multidirectional. The latest research is focused on the therapeutic and prophylactic effects of these compounds such as, for example, prevention of sclerotic changes in blood vessels and trapping of free radicals.

The polyphenols, especially those with ortho- or para-hydroxyl groups, were characterized by the facility of engagement in redox reactions. Due to their ability to transfer protons and electrons, not only do they undergo oxidation, but also take part in the oxidation of substrates that do not react with oxygen. Tannins are complex phenolic compounds with molecular weight in the range 3000–20,000 Da, classified either as hydrolysable or condensed, based on their structural types and their reactivity towards hydrolytic agents, particularly acids (Haslam, 1987). They are a group of compounds composed of 5–7 aromatic rings with 12–16 phenolic groups in a molecule. Hydrolysable tannins are esters of gallic acid or its derivatives. Condensed tannins are dimers, oligomers and polymers of flavan-3-ols which, upon acidic hydrolysis, produce anthocyanidins and are therefore known as proanthocyanidins. Tannins are one of the compounds that influence the sensoric quality of food.

Leguminous plants are cultivated throughout the world and consumed in various dishes. Their seeds are the source of many substances with antioxidant properties, including plant phenols. These compounds, universal in the world of plants, have been treated until very recently only as antinutritive factors. Lupin, because of the chemical composition of its seeds, like other legumes, is a potential source of bioactive plant components with antioxidant activities. Seeds of low alkaloid lupin varieties are a valuable source of proteins. Recently, it has been generally accepted that lupin protein can be an alternative to soybean. The interest in lupin as a valuable component of functional food is increasing and has led to investigation, which involves the determination of antioxidant activity in lupin and its products.

The seeds of the sweet lupin species contain less antinutritional compounds than other leguminous plants which significantly widens the spectrum of their potential application. The hull constitutes a considerable part of the lupin seeds (ca. 20%) with a high content of dietary fibre (50–54%) of good functionality (Górecka, Lampart-Szczapa, Janitz, & Sokolowska, 2000).

It is estimated that during storage the losses of leguminous seeds are at least 10%. A modern method of food conservation is irradiation. Until now this method has been used in 54 countries for preservation of over 224 food products. The FAO and WHO published data showing that an irradiation dose up to 10 kGy was safe for human health and did not cause adverse effects on nutritients in food processing. Of course, it is known that it can modify the biomolecules of food.

The aim of this study was to estimate the antioxidant properties of lupin seeds. We also tried to estimate dependences connected with the tocopherol and phenol compound contents, as well as the influence of the technological processes carried out (heating and radiation).

## 2. Materials and methods

### 2.1. Samples and chemicals

Seeds of lupin were purchased from the Plant Breeding and Acclimatization at Przebêdowo near Poznan (Poland). Vanillin and tocopherol standards were purchased from Merck, Darmstadt, Germany. Ethanol and acetone were purchased from POCh, Gliwice, Poland.

The examined lupin seeds of *Lupinus luteus* (Juno, Popiel, Aga, Piast), *Lupinus albus* (Wat, Bac- bitter), Bardo, and *Lupinus angustifolius* (Mirela-bitter, Sur, Wersal) differed in hull colour and in alkaloid content.

The flour was produced under industrial conditions. Samples of hulls were prepared in the laboratory. Seeds were ground in an impact mill and hulls isolated using a laboratory gravitation channel.

### 2.2. Treatment

For evaluation of the influence of temperature, the lupin flours were heated for 1 h at 105 °C. For studying the effect of the irradiation, doses of 1, 5 and 10 kGy of $^{60}$Co were used. Samples were stored 6 months in firmly closed boxes at $4\pm1$ °C.

### 2.3. Analysis

For all samples; dry matter content, protein ($N_{total}$ $\times 6.25$), and fat (Soxhlet method) were determined.

#### 2.3.1. Fatty acids

Composition was determined by GC in the fat extracted from samples after transestrification with 0.4N sodium methanolate (Wąsowicz, 1984). The GC analysis of FAME was carried out with a Hewlett-Packard 5890 II gas chromatograph equipped with flame ionization detector (FID) connected to the Hewlett-Packard integrator. The fused silica capillary column Supelcowax (30 m×0.25 mm×0.25 μm) was applied for the separation. The oven temperature was held at 210 °C. Hellium was used as carrier (1.5 ml/

min). The identification was done by comparison (of the retention data of the fatty acids separated from the samples) with those of the known standards (Rapeseed FAME Mix Sulpeco).

### 2.3.2. Tocopherols

These were determined by the HPLC method (Gogolewski, Nogala-Kalucka, & Szeliga, 2000). The HPLC system consisted of the Waters Model 600 gradient pump, fluorimetric detector and Waters Millenium data acquisition system. Samples dissolved in *n*-hexane were injected on the LiChrosorb Si 60 column (200 mm, 5 μm Merck), and the mixture of *n*-hexane and 2-propanol (99.5: 0.5 v/v) was used as a mobile phase. The flow rate was 1.5 ml/min. The concentrations were calculated from calibration curves made for individual tocopherols.

### 2.3.3. Polyphenols

These were detected as condensed tannins using the vanillin method (Swain & Hillis, 1959). For extraction of these compounds from the lupin samples 70% acetone was used and then distilled off in a vacuum evaporator.

### 2.4. Evaluation of the antioxidant properties

For evaluation of the antioxidant properties of lupin hulls were analyzed as well as flours. Ground lupin hulls were added directly to the melted lard (5 and 10%) and were kept in suspension in fat by magnetic stirrer in the Oxidograph (Larsen, 1989) at 110 °C. The same samples were tested by air bubbling in the Rancimat apparatus (Płatek, 1995) at 110 °C. The lupin flours were extracted four times with 80% ethanol (freshly distilled). The ethanol extract was added to the lard (0.1, 1%). Stability of the lard with antioxidant and control samples was also evaluated using the methods mentioned above.

Antioxidant efficiency in both methods was determined as the protection factor (PF), calculated as a ratio of the induction time of samples with lupin extracts added to the induction time of the control sample.

The results obtained were subjected to statistical analysis carried out using the computer program Statgrafics (Manugistic Inc., USA).

## 3. Results and discussion

### 3.1. Chemical composition

The results of the chemical analyses of the examined flours and hulls are presented in Tables 1–3. The protein and fat percentages in the examined flours were characteristic of the varieties of the *L. luteus* and *L. albus* species (Table 1). In the chromatographic analysis of the oil from the Juno and Wat varieties flours, alpha-, gamma- and delta-tocopherols were identified (Table 2). The tocopherol content was in inverse proportion to the fat quantity. The tocopherol content in the oil obtained from the flour of the yellow Juno variety was about 30% higher than in

Table 1
Contents of protein and fat in lupin flours and hulls

| Species/variety | Protein (% d.m.) | Fat (% d.m.) |
|---|---|---|
| *Flour* | | |
| *Lupinus luteus* | | |
| Juno | 59.1 | 5.10 |
| *Lupinus albus* | | |
| Wat | 43.5 | 10.6 |
| *Hull* | | |
| *Lupinus luteus* | | |
| Popiel | 3.70 | 1.38 |
| Aga | 4.10 | 1.20 |
| Piast | 3.44 | 1.27 |
| *Lupinus albus* | | |
| Bac | 3.57 | 1.58 |
| Bardo | 4.00 | 1.17 |
| *Lupinus angustifolius* | | |
| Mirela | 4.93 | 1.46 |
| Sur | 3.90 | 1.16 |
| Wersal | 4.62 | 1.24 |

Table 2
Contents of homologous tocopherols in lupin oil

| Tocopherol | *L. luteus* var. Juno | | *L. albus* var. Wat | |
|---|---|---|---|---|
| | % | %[a] | % | %[a] |
| alpha- | 0.009 | 3.2 | 0.005 | 2.8 |
| gamma- | 0.232 | 88.5 | 0.160 | 86.1 |
| delta- | 0.0223 | 8.3 | 0.021 | 11.1 |
| Total | 0.264 | | 0.186 | |

[a] Percentage of homologue in total contents of tocopherols.

Table 3
Contents of tannins in lupin flours and hulls

| Species/variety | Tannins (as catechin, mg/g) | |
|---|---|---|
| | Flour | Hull |
| *Lupinus luteus* | | |
| Popiel | 0.022 | 0.0016 |
| Piast | 0.027 | 0.0016 |
| *Lupinus albus* | | |
| Wat | 0.031 | 0.0012 |
| Bac | 0.077 | 0.0086 |
| *Lupinus angustifolius* | | |
| Mirela | 0.016 | 0.0030 |
| Wersal | 0.013 | 0.0030 |

Table 4
Effect of heating of lupin flour (*L. luteus* var. Juno) on antioxidant activity (PF) of its ethanol extracts (Oxidograph)

| Concentration (%) | Protection factor[a] | |
|---|---|---|
| | Raw | Heated |
| 0.1 | 1.76 | 1.76 |
| 0.2 | 2.30 | 2.63 |
| 0.5 | 2.82 | 2.80 |
| 1.0 | 4.78 | 4.83 |

[a] Means of three replicates.

the Wat variety of the *L. albus* species which can be characterized as the highest fat content among lupins (apart from *Lupinus mutabilis)*. In both of the species, as in other oil plants, there is domination of the gamma-tocopherol, and there was more gamma-tocopherol in the yellow variety (88.5%) than in the white variety (86.1%). According to Hatzold, Elmadfa, and Gross (1983) there are alpha- (3.8%) and gamma-tocopherol (96.2%) homologues present in the lupin, but Souza, Feldheim, Marquand, and Gross (1989) identified only the gamma- and delta-tocopherols. The results suggest that lupin vitamin E content is similar to that of soybean but lower than sunflower or rapeseed oil.

Table 3 suggests that all the lupin flours had contents of tannins a few times higher than the corresponding hulls. The highest content of these compounds was found both in the flour and in the hull of the white, bitter Bac variety. Among the flours the lowest amount of tannins was found in the examined *Lupinus angustifolius* varieties.

### 3.2. Antioxidant efficiency

The processes of oxidation and reduction in biological systems may be enzymatically catalyzed. To exclude this possibility, the lupin flour was heated prior to studying of the antioxidant properties. The antioxidant activity of the lupin flours was estimated on the basis of the test with the Oxidograph equipment. Ethanol extracts obtained from the lupin seed flour of the Juno variety were added to the lard in the concentrations of 0.1, 0.2, 0.5 and 1%; the results are presented in Table 4.

Heating of the flour did not significantly change the antioxidant effectiveness of the obtained ethanol extracts, but there is an advantageous rise tendency. The value of the protection factor rose, along with the quantity of the addition. It rose three times, comparing the lowest quantity of addition to the highest.

Having learned the lupin antioxidant effectiveness we decided to check how it was going to change after preservation of seeds by radiation, which is a method used for food products in many European countries.

### 3.3. Influence of gamma-irradiation

Results obtained in this study, demonstrating the influence of gamma-irradiation on the antioxidant activity, are shown in Table 5. For this study, the flour of Wat, of *L. albus,* the richest in fat among the lupin species, was chosen. The effect of irradiation on the storage of the lupin flour was analyzed using Oxidograph and Rancimat.

During the Rancimat test, all analyzed samples displayed the ability to inhibit oxidation of the lard, but the greatest activity was noted in the control sample. Increase of the radiation dose caused decrease of the antioxidant activity. The samples irradiated with a 10 kGy dose and their extracts, tested at a concentration of 0.1%, exhibited slight prooxidant effects. After six months of storage of the irradiated flours the antioxidant activity of their ethanol extracts was slightly lower at the concentration of

Table 5
Effect of irradiation and storage of lupin flour (*L. albus* var. Wat) on antioxidant activity (PF) of its ethanol extracts in lard evaluated by Rancimat and Oxidograph tests

| Dose [kGy] | Protection factor | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Rancimat | | | | Oxidograph | | | |
| | Storage time | | | | Storage time | | | |
| | 1 month | | 6 months | | 1 month | | 6 months | |
| | Addition (%) | | Addition (%) | | Addition (%) | | Addition (%) | |
| | 0.10 | 1.00 | 0.10 | 1.00 | 0.10 | 1.00 | 0.10 | 1.00 |
| 0 | 1.24±0.07b[a] | 1.85±0.13c | 1.28±0.09b | 2.52±0.23b | 0.87±0.03a | 1.19±0.09a | 1.97±0.61c | 2.12±0.51ab |
| 1 | 1.37±0.04c | 1.48±0.09b | 1.22±0.06b | 2.36±0.30b | 1.18±0.09b | 1.64±0.12b | 1.35±0.13b | 2.25±0.69b |
| 5 | 1.19±0.09b | 1.36±0.11b | 1.06±0.02a | 1.93±0.24a | 1.34±0.08c | 1.80±0.13b | 0.77±0.05a | 1.42±0.26a |
| 10 | 0.83±0.03a | 1.01±0.05a | 1.07±0.07a | 1.74±0.09a | 0.92±0.03a | 1.21±0.09a | 1.00±0.08ab | 1.97±0.17ab |

[a] Means of three replicates followed by the same letter within columns are not significantly different at $P \leqslant 0.05$.

0.1%. However, in the samples tested at a concentration of 1%, higher activity was observed directly after irradiation. The influence of the irradiation dose was more significant for antioxidant properties at that concentration and for the mean value of protector factors at both concentrations (Table 5).

In the Oxidograph test, the above tendency was not so clear. Extract obtained from the control sample had slight prooxidant activity at the low concentration. The highest activity was found for the sample irradiated with 5 kGy. Similar to the results found during the Rancimat measurement, antioxidant activity, generally, was higher after 6 months of storage, than after 1 month. Contrary to the effect at the beginning, the sample irradiated with 5 kGy showed the lowest antioxidant activity at both concentration studied (Table 5). Different results found in both tests used in this work (Rancimat and Oxidograph) could be caused by different procedures and the rate of oxidation measurement, i.e. oxygen uptake in the Oxidograph and formation of carboxylic compounds as a products of oxidation in the case of the Rancimat.

Increase of the irradiation dose from 1 to 10 kGy caused a decrease of the tocopherol contents down to 62.8, 17.8 and 11.1%, respectively (Table 6). It was found that the observed negative changes in tocopherol contents are the effects of the storage time as well as the dose of irradiation of the flour. However, a lower dose of irradiation (1 kGy) caused about 20% decrease of tocopherols after 1 month of storage and another 20% after 6 months. In the control flour sample, after 6 months, only 15% loss of tocopherols was observed. Percentage composition of tocopherol homologues in the control lupin flour was: alpha-T, 6.8%, gamma-T, 88.0%, delta-T, 5.3%. During storage, changes were observed in the composition of tocopherols in all of the analyzed flour samples. Generally, a tendency to increase the percentage content of delta-T was seen. After 6 months of storage, the increase of delta-T was as follows; for 1 kGy, up to 9.63%, for 5 kGy, 17.10% and for 10 kGy, 20.12. Similar observations have been reported earlier (Gogolewski, Jasińska-Stępniak, Bartowiak, & Galuba, 1997). The increase in delta-T is beneficial, since this homologue is recognized as the most active native antioxidant among all other tocopherols (Elmadfa & Wagner, 1997). So, this investigation suggested the possibility that the remarkable decrease of the tocopherol content did not significantly influence the changes of the antioxidant properties of the irradiated flours. Apart from tocopherols present in the extract of the lupin flour investigated, it can also contain other compounds with antioxidant properties, for example plant phenols, not considered in this part of the presented study.

From the nutritional point of view, it also seemed interesting to check whether the gamma radiation modified the lupin fatty acid contents. The results presented in the Table 7 point to the conclusion that this process does not cause any important changes in the percentage content of the fatty acids, so, in this respect, it is a safe process.

In conclusion, the lupin flour preserved by irradiation can be considered as a functional food additive, retarding the development of oxidative changes during storage.

### 3.4. Lupin hulls

Compared to other leguminous crops, lupin seeds have a large proportion of hulls, which can be a source of valuable health promoting ingredients, including those with antioxidant properties. Therefore lupin hulls were estimated.

Table 6
Changes of tocopherol contents in irradiated lupin flour (*L. albus* var. Wat)

| Dose/time of storage | α-Tocopherol | | γ-Tocopherol | | δ-Tocopherol | | Total | |
|---|---|---|---|---|---|---|---|---|
| | mg/100 g of oil | % of total | mg/100 g of oil | % of total | mg/100 g of oil | % of total | mg/100 g of oil | % of total |
| *0 kGy* | | | | | | | | |
| 1 month | 5.35 | 6.78 | 69.4 | 88.0 | 4.11 | 5.20 | 78.9 | 100 |
| 6 months | 3.43 | 5.13 | 57.9 | 86.6 | 5.50 | 8.20 | 66.8 | 84.7 |
| *1 kGy* | | | | | | | | |
| 1 month | 4.99 | 7.90 | 53.8 | 85.6 | 4.03 | 6.40 | 62.8 | 79.6 |
| 6 months | 1.58 | 3.13 | 43.9 | 87.2 | 4.85 | 9.63 | 50.4 | 63.8 |
| *5 kGy* | | | | | | | | |
| 1 month | 3.32 | 18.7 | 12.5 | 70.2 | 1.97 | 11.1 | 17.8 | 22.5 |
| 6 months | 0.81 | 4.35 | 14.6 | 78.5 | 3.18 | 17.1 | 18.6 | 23.6 |
| *10 kGy* | | | | | | | | |
| 1 month | 0.55 | 4.94 | 8.94 | 80.3 | 1.64 | 14.7 | 11.1 | 14.1 |
| 6 months | 0.56 | 4.74 | 8.37 | 74.9 | 2.25 | 20.12 | 11.2 | 14.2 |

Table 7
Fatty acid composition of oil from irradiated lupin flour (*L. albus* var. Wat)

| Fatty acid (%) | Dose | | | |
|---|---|---|---|---|
| | 0 kGy | 1 kGy | 5 kGy | 10 kGy |
| $C_{14:0}$ | 0.08 | 0.09 | 0.09 | 0.09 |
| $C_{15:0}$ | 0.05 | 0.06 | 0.05 | 0.06 |
| $C_{16:0}$ | 5.67 | 6.02 | 5.82 | 5.91 |
| $C_{16:1}$ | 0.31 | 0.34 | 0.33 | 0.33 |
| $C_{18:0}$ | 1.75 | 1.75 | 1.75 | 1.79 |
| $C_{18:1}$ | 53.0 | 52.8 | 52.8 | 53.1 |
| $C_{18:2}$ | 21.4 | 21.6 | 21.6 | 21.3 |
| $C_{18:3}$ | 8.30 | 8.39 | 8.31 | 8.04 |
| $C_{20:0}$ | 1.06 | 1.01 | 1.04 | 1.06 |
| $C_{20:1}$ | 3.71 | 3.57 | 3.65 | 3.65 |
| $C_{22:0}$ | 3.01 | 2.94 | 3.09 | 3.09 |
| $C_{22:1}$ | 1.27 | 1.37 | 1.47 | 1.48 |

Table 8
Induction period (h) in Oxidograph and Rancimat tests with lupin hulls addition

| Species/variety | Oxidograph | | Rancimat | |
|---|---|---|---|---|
| | 5% | 10% | 5% | 10% |
| *Lupinus luteus* | | | | |
| Popiel | 3.3±0.2c[a] | 3.2±0.3b | 3.73±0.07c | 4.18±0.24b |
| *Lupinus albus* | | | | |
| Bardo | 3.2±0.1c | 3.6±0.1c | 3.22±0.10b | 3.84±0.04b |
| *Lupinus angustifolius* | | | | |
| Mirela | 2.7±0.1b | 3.0±0.1b | 3.62±0.08c | 4.12±0.21b |
| Control | 1.75±0.19a | | 2.51±0.26a | |

[a] Means within columns followed by the same letter are not significantly different at $P \leqslant 0.05$.

The process of dehulling the lupin seeds is more complicated than it is in other leguminous species. This results from the characteristic shape of the seed, considerable thickness and resistance of the hull and differences among cultivars. It is known, that the chemical composition of the hull, obtained after grinding the seeds, depends to some extent upon the method of obtaining it. Results presented above have shown that lupin cotyledons are a source of antioxidant components, therefore seeds of the varieties used in this study were ground, so as to deprive the hull of as much of the residue of cotyledons as possible. The hulls of the cultivars studied contained 3.44–4.62% of protein and 1.16–1.58% raw fat (Table 1). These results are markedly lower than those achieved in other studies in which mechanical dehulling on a semi-technical scale was employed (Zduñczyk, Juskiewicz, & Flis, 1995). As earlier, the antioxidant activity of lupin hulls was evaluated instrumentally in lard, with the use of Rancimat and Oxidograph, on the basis of two different ways of measuring the lipid stability. Samples of the hull were added directly to the melted lard (5 and 10%) and were kept in suspension in fat by magnetic stirrer in the Oxidograph and by air bubbling in the Rancimat. Both tests proved that the hull from all three studied lupin species increased the induction period in lard (Table 8). Greater amounts of the hull added, extended the induction period only in the Rancimat test, where the lard stability was significantly higher with the 10% addition. Induction periods of the control samples and of the samples with the hull added were used to calculate the antioxidant efficiency (Table 9). Protection factors for the evaluated lard samples were higher in the Oxidograph than in the Rancimat test. The results obtained point to significant inhibition of the rate of lard oxidation by the lupin hull.

Antioxidant activities of the lupin cultivars tested were similar and did not depend either on the colour of the hull or the content of polyphenols which was observed in other studies (Wilska-Jeszka & Stasiak, 1994). Their PF values were 2.08 to 1.71 (Table 9).

Table 9
Antoxidant efficiency of samples with 10% of lupin hulls addition determined by protection factor (PF)

| Species/variety | Colour of hulls | Oxidograph | Rancimat |
|---|---|---|---|
| *Lupinus luteus* | | | |
| Popiel | Light beige | 1.82±0.16ab[a] | 1.67±0.09e |
| Aga | Light grey | 2.03±0.18b | 1.51±0.11cde |
| Piast | Light grey | 1.84±0.18ab | 1.39±0.13bc |
| *Lupinus albus* | | | |
| Bac | Light beige | 1.79±0.08a | 1.10±0.04a |
| Bardo | Light beige | 2.08±0.3b | 1.53±0.04cde |
| *Lupinus angustifolius* | | | |
| Mirela | Light beige | 1.71±0.04a | 1.64±0.08de |
| Sur | Dark grey | 1.78±0.08a | 1.31±0.07b |
| Wersal | Light grey | 1.81±0.23a | 1.44±0.14bcd |

[a] Means within columns followed the same letter are not significantly different at $P \leqslant 0.05$.

Hulls of the Bardo and Mirela varietes of the same light-beige colour were characterized by the highest and the lowest antioxidant activities, respectively. Their PF values were 2.08 and 1.71, respectively (Table 9).

Hulls of the Bac and Popiel varieties seeds have similar antioxidant activities and the same light colour. But the tannin content in the hull of the Bac variety is four times higher than in the hull of Popiel variety and the highest among all examined varieties.

## 4. Conclusions

Results of the research displayed the antioxidant activity of both the lupin flour and the hulls. Correlation between the antioxidant properties and the contents of the natural lupin antioxidants, such as tocopherols and tannins, was not found.

Lupin flour, preserved by irradiation, can be considered as a functional food additive, preventing negative oxidative changes during storage.

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