Comparative study of lipase preparations for enzymatic degumming of sunflower oil

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Abstract

Introduction. Degumming is a crucial stage in the production of refined vegetable oil. Enzymatic degumming has been applied as a mean to improve process efficiency, and currently, many new lipase preparations are available. The present study aimed to assess the efficiency of their application on the degumming process of sunflower oil.

Materials and methods. Enzyme preparations Lecitase® Ultra, Quara® Boost, and Quara Low P were received from Novozyme (Denmark). Phosphorus content in oil ash was detected photometrically. Acid, peroxide, and saponification values were determined by standard methods. Antioxidant properties of the oil were estimated based on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity.

Results and discussion. Enzymatic degumming of sunflower oil results in an increase in oil yield compared with water degumming. Degumming with Quara® Boost preparation results in 98% oil yield, which was 1.5% higher than in the case of water degumming. Using Lecitase® Ultra and Quara Low P increased oil yield by 1 and 0.5%, respectively, compared with water degumming. The phospholipid content decreased from 0.4% in crude oil to 0.2% after water degumming, meanwhile, the application of enzyme preparations Lecitase® Ultra and Quara Low P reduced the content of phospholipids to 0.08% and 0.06%, respectively. The lowest phospholipid content, 0.04%, was in the sunflower oil after degumming with phospholipase C (Quara® Boost), which corresponds to 16 mg of phosphorus per kg of oil. The saponification value of sunflower oil degummed with phospholipase C preparation proved the formation of diacylglycerols in oil, 191.5 mg KOH/g. The highest free fatty acid content in sunflower oil was after degumming with Lecitase® Ultra: the acid value increased from 0.86 mg KOH/g in crude oil to 2.7 mg KOH/g in degumming oil. However, Quara Low P preparation also has phospholipase A1 activity, so, the acid value decreased slightly compared with crude oil. Degumming with Quara® Boost preparation did not affect the free fatty acid content in sunflower oil, and the acid value was even lower than in the oil degummed with water. The peroxide value of sunflower oil was <1 meq O/kg after enzymatic degumming, meanwhile the peroxide value of sunflower oil after water degumming was 2.6 meq O/kg. All oil samples had a similar antioxidative capacity that was 30-36% of scavenged DPPH$^{\cdot}$ radical.

Conclusions. The most effective enzyme preparation for sunflower oil degumming was Quara® Boost with phospholipase C activity. Application of Quara® Boost results in the highest oil yield, the lowest content of phospholipids and free fatty acids, low peroxide value, and high antioxidant capacity of oil.

Introduction

Phospholipids of vegetable oil are valuable substances, which can positively impact human health when included in a diet (Xie, 2019). They also have outstanding functionality and could be used as emulsifiers in food systems. Depending on the kind of vegetable oils and the method of their production, they contain 0.3–2.5% phospholipids (O'Brien, 2004). The solvent-extracted oils contain more phospholipids than the pressed oils (Wang and Johnson, 2001). However, the presence of phospholipids negatively affects such stages of oil processing as neutralization, bleaching, deodorization, and hydrogenation (Hamm et al., 2013).

The phospholipids are polar lipids and their solubility is not sufficiently stable and depends on their hydrophilicity. The solubility of a phospholipid molecule in oil decreases as its hydrophilicity increases. In addition, the phospholipids may lose their solubility and form a precipitate in vegetable oils during crude oil storage (Hamm et al., 2013).

While phospholipids are typically considered undesirable in oil processing, they can still be utilized as valuable additives in food or feed production. Thus, modern processing of vegetable oils includes the stage of phospholipid removal, which is also known as oil degumming. Traditionally, phospholipids are removed by water or acid degumming followed by alkaline refining. Only part of the more polar phospholipids is removed by water treatment. Such a group of phospholipids is called hydratable. The other part of the phospholipids could not be removed by water treatment, and therefore, acid degumming is required to remove hydratable and non-hydratable phospholipids from oil. Nonetheless, acid degumming is not a sustainable method of oil processing (Hamm et al., 2013).

The use of enzymes in the food industry is noted as ongoing a developing area in advanced food production technology (Ivanov et al., 2021). The Lurgi Company first proposed enzymatic degumming Aalrust et al., 1992). This method allows converting of non-hydratable phospholipids into hydratable ones increasing oil yield and reducing the application of chemicals, generation of wastes, consumption of energy, and overall costs compared with traditional degumming (Loren et al., 2014) as well as ensures low phospholipid content in the treated oil.

Enzymes such as phospholipase A (PLA), phospholipase C (PLC), and mixtures of phospholipase C and A (PLC/PLA) currently are used for enzymatic degumming (Dijkstra, 2010). Phospholipases of the A type hydrolyze phospholipids producing lysophospholipids and free fatty acids (Heinze et al., 2013). Phospholipase A1 (PLA1) and phospholipase A2 (PLA2) remove the fatty acid from positions 1 and 2 respectively with respect to glycerol (Figure 1, adapted from Guiotto et al., 2015). Phospholipases of the C type hydrolyze phospholipids into diacylglycerol and phosphoric esters (Semproli et al., 2021).

Initially, only two enzyme preparations, such as Lecitase® 10L (porcine pancreas) with PLA2 activity and Lecitase® Novo (microbial lipase produced by fungi *Fusarium oxysporum* and *Thermomyces lanuginose*) with PLA1 activity were used in the industry for oil degumming (Guerrand, 2017). Recently, phospholipase C (Purifine®) and lipid acyl transferase (LysoMax®) with PLA2 activity have also become commercially available. These enzymes have different specificities (Dijkstra, 2010). The Lecitases® and the LysoMax® enzymes catalyze the hydrolysis of all common phospholipids and differ in this respect from the Purifine® enzyme, which is specific for phosphatidyl choline and phosphatidyl ethanolamine. These phospholipids are hydrolyzed to oil-soluble diacylglycerol and water-soluble phosphate esters. Since diacylglycerols remain in the oil during refining, they contribute to the oil yield. The sterol and stanol esters formed as a consequence of the phospholipid hydrolysis catalyzed by the LysoMax® enzyme. In addition, all enzymes result in less oil being emulsified by the gums, which also contributes to an oil yield increase.

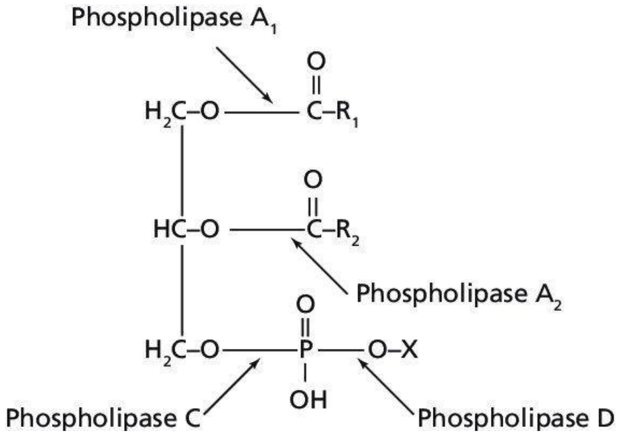

Figure 1. Action of different types of phospholipases (Adapted from Guiotto et al., 2015)

The Lecitase® Ultra enzyme is a microbial lipase (E.C.3.1.1.3) from *Thermomyces lanuginosus/Fusarium oxysporum,* which exhibits phospholipase A1 activity maximally at pH5.0 and can hydrolyze phospholipids as well as triacylglycerols. When the temperature is over 40°C, the phospholipase activity predominates, and the lipase activity is partly suppressed (Yang et al., 2006). It was shown that degumming of rapeseed and soybean oil with Lecitase® Ultra for 5 hours at 50 °C resulted in a phospholipids content of less than 10 mg/kg. Similar results were obtained by Sampaio et al., (2015) during enzymatic degumming of the same oil with a Lecitase Ultra®. The phosphorus content in a degummed oil was less than 10 mg/kg at an enzyme dosage of 30 mg/kg and a treatment time of 10–120 min. While a good degumming efficiency can already be obtained after a relatively short reaction time, it was observed that a longer reaction time, 1–2 hours, is required for the degradation of all phospholipids, which results in an oil yield increase. It was shown that Lecitase Ultra® has no specificity for phospholipids, but the rate of different phospholipids conversion is various. After 60 min, 80% of phosphatidylethanolamine was hydrolyzed to its lysoform, while only 40% of phosphatidylinositol was converted during the same time.

Contrary to common belief, it was suggested that the enzymes were incapable catalyzing the hydrolysis of non-hydratable phosphatides under industrial conditions (Dijkstra, 2010). However, the subsequent study did not confirm this suggestion and indeed demonstrated the decrease of phosphorus content in crude oil to < 10 mg/kg during the enzymatic degumming trial (Yang B. et al., 2006; Yang et al., 2008).

An enzymatic degumming of soybean oil was carried out at a capacity of 400 tons/day by applying microbial phospholipase A1 from *Thermomyces lanuginosus/Fusarium oxysporum* (Yang et al., 2008). The phosphorus content in oil was less than 10 mg/kg when the pH was in the range of 4.8–5.1, and the oil loss was minimal under these conditions. It was shown that content of glycerophospholipids and lysophospholipids in the gums was 45.7 and 54.3%, respectively.

Similar results were obtained for rapeseed oil at the degumming plant (Yang B. et al., 2006). Response surface methodology was used for the optimization of the enzymatic degumming process. Enzyme dosage, temperature, and pH were important determining factors, affecting oil degumming. The optimal set of variables was an enzyme dosage of 39.6

mg/kg, a temperature of 48.3°C, and a pH of 4.9. The phosphorus content could be reduced to 3.1 mg/kg at the optimal levels of the tested factors. At the enzymatic degumming plant, when the pH was 4.6 to 5.1, the corresponding phosphorus content of degummed rapeseed oil could be reduced to less than 10 mg/kg, which met the demands of the physical refining process. In another study, the efficiency of enzymatic degumming was assessed using the same Lecitase®-Ultra with different qualities of crude rice bran oil. The phosphorus content in the oil was reduced to ~10 mg/kg from an initial level of 390 mg/kg after 2 h of incubation at 50°C (Manjula et al., 2011).

A comparison of enzymatic degumming of screw-pressed crude jatropha oil with Lecitase Ultra (phospholipase A1) and LysoMax (phospholipase A2) demonstrated that degumming with phospholipase A2 was less effective (Gofferjé et al., 2014). Phospholipase A1 showed the highest reaction rate at 50 °C, 700 rpm stirring, 3 mL of water per 100 g of oil, and with 75 mg/l of added phospholipase, the pH was adjusted to 5. Laboratory experiments showed that enzymatic degumming of jatropha oil with phospholipase A1 at the adapted parameters enables the phosphorus content to be reduced to a level below 4 mg/l.

For industrial applications enzymatic activity of phospholipase A1 was improved by protein engineering (An et al., 2017). Obtained mutants had higher phospholipase activity and identical optimal pH values with wild-type, while the optimal temperature was decreased to 50°C, and the k_{cat}/K_M was improved. Modified lipases decreased phosphorus content lower than 8.3 mg/kg within 3 h, which was highly improved compared with the wild-type. One mutant decreased phosphorus content to less than 5 mg/kg within 5 h.

Recently, new lipase preparations appeared on the market, particularly Novozyme Quara® Boost (phosphoinositide phospholipase C and phospholipase C) and Novozyme Quara Low P (phospholipase A1). Since every enzyme has a specific affinity for different types of phospholipids, it is necessary to study the peculiarities of oil degumming by each lipase preparation, taking into account the properties of the oil, such as the composition of phospholipids. However, there is currently a lack of information regarding the effectiveness of enzyme preparations in degumming sunflower oil. Therefore, this study aimed to investigate the influence of a new lipase preparation on the degumming of sunflower oil.

Materials and methods

Enzyme preparations and oil sample

Enzyme preparations Lecitase® Ultra, Quara® Boost, and Quara Low P were received from Novozyme (Denmark). The properties of each enzyme are presented in Table 1.

Table 1

Characteristics of enzyme preparations

Enzyme	Characteristics
Lecitase® Ultra	A lipase produced by the genetically modified filamentous fungus *Aspergillus oryzae;* has phospholipase A1activity.
Quara® Boost	A lipase produced by the spore-forming bacterium *Bacillus licheniformis;* consists of two types of phospholipase C: phosphoinositide phospholipase C and phospholipase C.
Quara Low P	A lipase produced by ascomycetous fungus *Talaromyces leycettanus;* has phospholipase A1activity.

For enzymatic degumming, 0.5% enzyme solutions were prepared by dispersing the phospholipase in distilled water.

Enzymatic degumming

Crude sunflower oil was purchased from the local market. Crude sunflower oil, 100 g, was placed into a 250-ml conical flask. The oil was heated to about 60 °C followed by the addition of 5% of 0.5% enzyme solution in distilled water. The mixture was thoroughly mixed for 1 min and stirred at 60 °C for 1 h. The enzymatic degumming reaction was followed by enzyme inactivation at 80 °C for 10 min. After that reaction mixture was kept for 30 min at room temperature. The 10 ml of the reaction mixture was put into a graduated centrifuge tube and the gums were separated from the oil by centrifugation at 2000 rpm for 10 min. The control sample was prepared in the same way using 5% water for degumming instead of enzyme solution.

Oil yield analysis

The volume of degummed oil was measured after gums separation and oil yield (X, % of crude oil) was calculated as:

$$X = (b/9.52) \cdot 100,$$

where 9.52 was the volume of the crude oil in 10 ml degumming mixture before centrifugation in ml, and b was the volume of separated oil in ml.

Phosphorus content analysis

The oil samples were ashed for phosphorus content determination according to (Yang. et al., 2006). 0.7 g of MgO and 0.6 to 0.7 g of oil were weighed and heated in the oven at 110 ^{0}C for 10 min. After that, the samples were carbonized by heating on the hot plate and then ashed in an electric muffle furnace at 600 °C until a constant mass was achieved.

The phosphorus content of the ash was determined according to American Oil Chemists' Society (AOCS) method Ca 12–55 (1997). Cold ash was transferred to a 100 ml flask, 10 to 12 ml water, and 20 ml 2N H_2SO_4 were added. The solution was heated to dissolve the residue. After that 20 ml molybdenum reagent was added and the solution was heated in boiling water bass for 30 min. The volume of the cold solution was adjusted to 100 ml. Photometric analysis was carried out on photometer KPhK-3 (AS ZOME) at 750 nm.

A standard solution of KH_2PO_4 (concentration 10 µg/ml) was used for the calibration curve obtaining. The calibration solution set was prepared in the same condition as the ash samples. The concentration of KH_2PO_4 in the calibration solution set was adjusted from 0.05 to 2.0µg/ml.

Phosphorus content (P, % of oil mass) was calculated as follows:

$$P = 0.01\ d/m,$$

where d was the phosphorus content in ash solution according to a calibration curve, µg/ml; m was oil mass, g.

The content of phospholipids as stearoiloleil phosphatidylcholine (PC, % of oil mass) was calculated as follows:

$$PC = 25.4\ P$$

where P was the phosphorus content,% of oil mass; 25.4 was a coefficient for calculation of the stearoiloleil phosphatidylcholine mass on the base of phosphorus content.

Chemical parameters of oils

The acid value of oil samples was determined by the titrimetric method according to ISO 660:2020.

The oil's peroxide value was determined using the iodometric method according to ISO3960:2017.

The saponification value of the oil was determined by the titrimetric method according to ISO 3657:2020.

Antioxidant activity

The radical scavenging capacity was determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method (Uluata et al., 2012). For the DPPH test, DPPH was dissolved in a small volume of ethyl acetate and diluted with ethyl acetate by adjusting the absorbance to 0.700 ± 0.020 at 520 nm. 100 mg of oil was weighed in a test tube, and 15 ml DPPH$^•$ free radical solution was added. The sample was agitated and absorbance was measured at 520 nm against ethyl acetate. After 30 min of incubation in darkness absorbance was measured at 520 nm against ethyl acetate.

The results of the DPPH test were expressed as% of DPPH$^•$ free radicals that were scavenged by antioxidants in 100 mg oil (A, %):

$$A = (1 - D_1/D_0) \cdot 100,$$

where D_0- was the absorbance of the reaction solution at 520 nm before incubation, and D_1- was the absorbance of the reaction solution at 520 nm after incubation.

Statistical analysis

Each sample was analyzed in triplicate, and the results were reported as mean ± standard deviation. Differences were considered to be significant at validity α=0.95.

Results and discussion

Effect of enzymatic degumming on the sunflower oil yield

The oil yield is a crucial factor for determining the efficiency of the degumming process and overall oil refining. The yield of refined oil determines the profitability of vegetable oil production. The quantity of oil loss with gums is directly correlated with the oil yield, meaning that a higher oil yield results in less oil loss with gums.

According to our findings, the use of water as a degumming agent resulted in the lowest oil yield (Figure 2).

Enzymatic degumming results in higher oil yield compared with water degumming. The highest oil yield was found from the degumming process with the enzyme Quara® Boost (98%), followed by Lecitase® Ultra (97.5%) and Quara Low P (97%).

Our results do not completely agree with the Novozyme company data which had reported about 0.9 and 0.6% higher yield of soybean and rape seed oil, respectively, after degumming with Quara Low P compared to Lecitase® Ultra degumming. Different results of Lecitase® Ultra and Quara Low P action on sunflower oil degumming could be explained by the composition of phospholipids in this oil (Lilbæk et al., 2017).

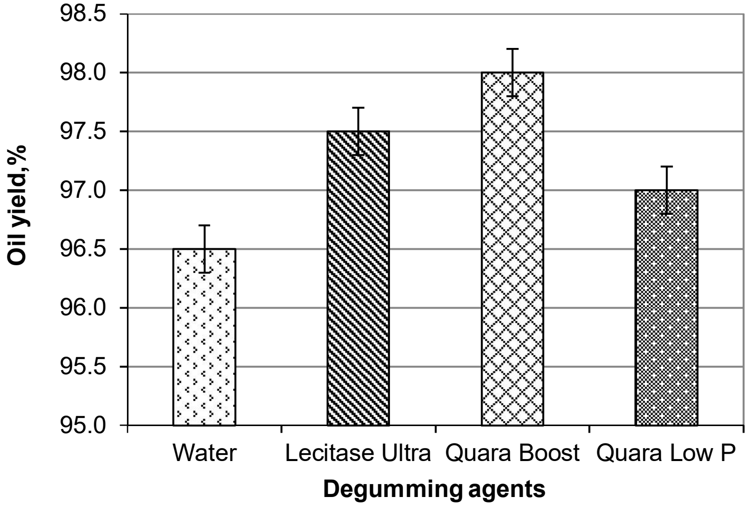

Figure 2. Effect of enzyme degumming on the sunflower oil yield

The increase of oil yield under degumming with phospholipase C (Quara® Boost) is due to diacylglyceride formation and their remaining in the oil. Degumming with phospholipase A1 (Lecitase® Ultra and Quara Low P) results in free fatty acids release. Despite the same enzyme activity, mainly phospholipase A1 activity, the advantages of Quara Low P are its thermal stability (denaturation temperature is around 80 °C) and an optimal low pH range of around 4. In addition, the increase in oil yield was due to a decrease in oil quantity in gums as a result of emulsification for both types of phospholipase.

Effect of enzyme degumming on the content of phospholipids in sunflower oil

The content of phospholipids in degummed oil is an indicator of the efficiency of the degumming capacity. The content of phospholipids in all oil samples decreased as a result of degumming (Figure 3).

Obtained results demonstrated, that about half of the phospholipid content in sunflower oil is hydratable phospholipids. The phospholipids content decreased from 0.4% in crude oil to 0.2% in water-degummed oil. Adding enzyme preparation decreased phospholipids content significantly. The lowest phospholipids content was in the sunflower oil after degumming with phospholipase C (Quara® Boost), that is 0.04% of stearoiloleillecitin, which, in turn, corresponds to 16 mg phosphorus /kg of oil. The degumming with Lecitase® Ultra and Quara Low P reduced phospholipids content to 0.08% and 0.06%, respectively.

Previously, even lower phosphorus content was shown in soybean and rape seed oil after Lecitase® Ultra enzyme degumming (Sampaio et al., 2015; Yang B. et al., 2006; Yang et al., 2008). The phosphorus content in these oils was less than 10 mg/kg after Lecitase® Ultra enzymatic degumming. Moreover, the authors (Yang B. et al., 2006) received rape oil with content 3.1 mg phosphorus /kg after optimization of degumming parameters. Noteworthy, the time of enzyme treatment was very different in this research, reaction time varied from 5 hours to 1 hour. According to our results, it was obvious that a duration of 1-2 hours is sufficient for phospholipid content decrease.

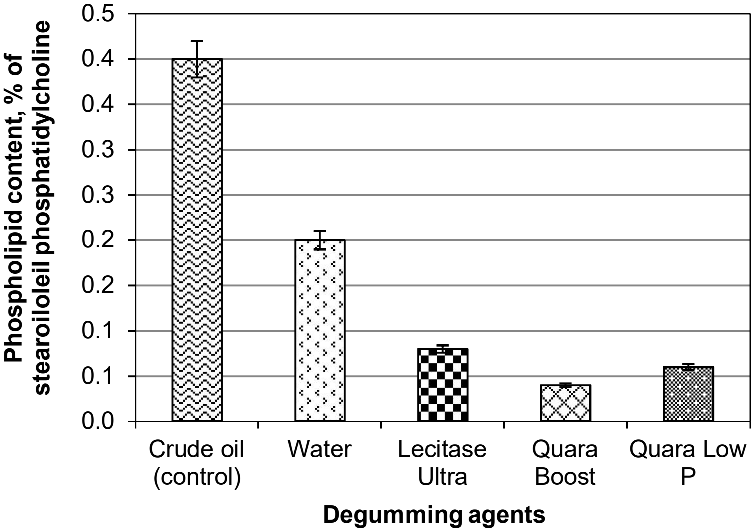

Figure 3. Effect of enzymatic degumming on phospholipids content in sunflower oil

Significant decrease of the phospholipid content in sunflower oil din the presence of phospholipase C is due to production of the hydrophobic diacylglycerols (they remain in oil), and hydrophilic phosphate esters, which are moved to the gums. At the same time, it is possible that not all lysophospholipids, which are forming under the action of phospholipase A1, have high hydrophilicity and are moving to the gum precipitate. Such lysophospholipids contain fatty acid residuals and accordingly have some affinity to triacylglycerol. This can be the reason for higher phospholipids content in sunflower oil after enzymatic degumming with phospholipase A1 preparation.

Higher effectiveness of new phospholipase A1 preparation Quara Low P corresponds to Novozyme data. According to these data phospholipids content in soybean oil was in the range of 3.1 to 4.6 mg/kg phosphorus after enzyme degumming in the presence of Quara Low P (Lilbæk et al., 2017).

The formation of diacylglycerols in oil after degumming with phospholipase C preparation was proved by the decrease in the saponification value of sunflower oil (Table 2). This sample of sunflower oil had the lowest saponification value which is the lowest content of ester bounds. The saponification values of sunflower oil after degumming with phospholipase A1 preparations were lower than the oil sample after water degumming.

Table 2

Saponification value of sunflower oil

Oil sample	Saponification value, mg KOH/g
Crude oil	220.5±3.4
Water degumming	204.1±2.4
Lecitase Ultra degumming	195.8±3.7
Quara Boost degumming	191.5±3.2
Quara Low P degumming	196.6±4.4

Effect of enzyme degumming on the free fatty acids content in the degummed oil

It is known that water degumming can remove acid phosphatides from oil and, as a result, acid value of oil decreases (O'Brien, 2004). According to our data acid value of sunflower oil was reduced after water degumming (Figure 4).

It is obvious that phospholipase A1 enzymatic degumming will increase free fatty acids content in the oil. Indeed, our results revealed that acid value had increased significantly after degumming with Lecitase® Ultra, which means acid value increased from 0.86 mg KOH/g in crude oil to 2.7 mg KOH/g after Lecitase® Ultra degumming. Remarkably, under the action of Quara Low P preparation, which has also phospholipase A1 activity, the acid value decreased slightly compared with crude oil.

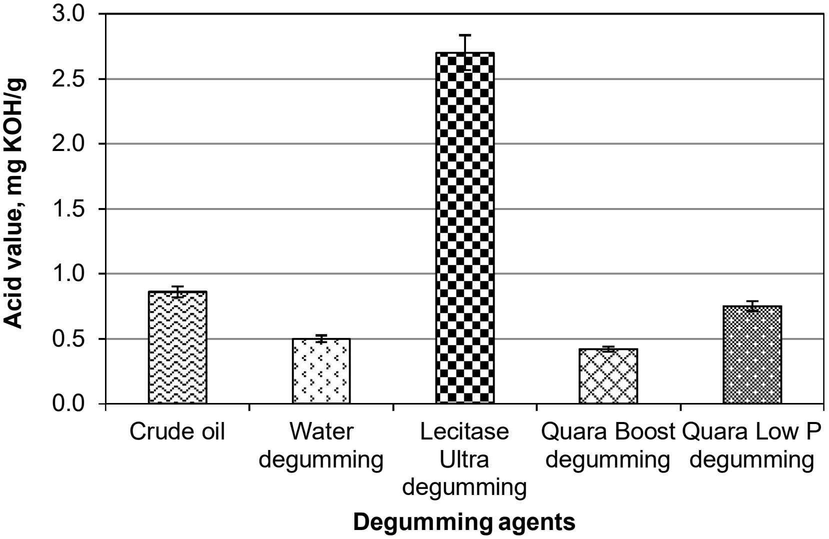

Figure 4. Effect of enzymatic degumming on the acid value of sunflower oil

It could be suggested that such a remarkable increase of oil acidity under Lecitase® Ultra degumming could be due to the activity of this preparation toward triacylglycerol hydrolysis. Although the phospholipid content of two oil samples after phospholipase A1 degumming was very close, triacylglycerol hydrolysis can be responsible for that big acidity difference between these oil samples.

Degumming with Quara® Boost preparation resulted in the lowest free fatty acids content in sunflower oil: the acid value had decreased twice compared with crude oil. We suggest this is due to removing of acid phosphatides from the oil.

Effect of enzymatic degumming on the oxidative stability of the oil

The important property of vegetable oils is their oxidation stability, which depends on many factors such as the composition of fatty acids, the content of antioxidants, and the content of oxides and peroxides (Demidova et al., 2019, Nosenko et al., 2019).

The important indicator of oil oxidation degree and peroxide content is the peroxide value. The peroxide values of sunflower oil after degumming with studied enzyme preparations were significantly lower. The peroxide value of sunflower oil after water degumming was almost two times lower compared with crude oil (Figure 5).

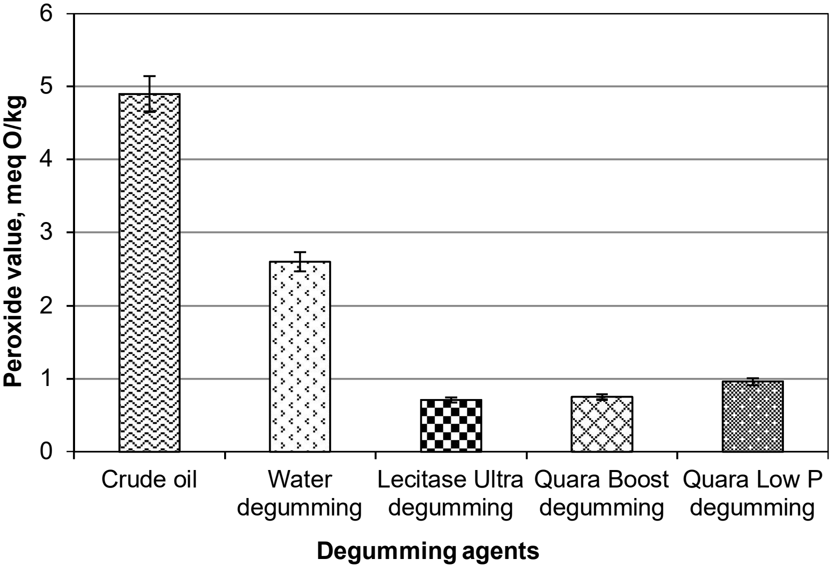

Figure 5. Effect of enzymatic degumming on peroxide value of sunflower oil

Peroxide content had reduced heavily in oil samples due to enzymatic degumming. The peroxide value of enzymatic degummed oil samples was <1 meq O/kg, which means a very low content of peroxides. The peroxide value of water-degummed sunflower oil was significantly higher compared with oil samples after enzymatic degumming.

At the same time, other data about the influence of enzymatic degumming on the oil's oxidative stability had been reported. The authors had shown an increase in the peroxide value of sunflower oil after treatment with phospholipase A1 (Lamas et al. 2014) and a decrease in oxidative stability of rapeseed oil after degumming with phospholipase C (Ye et al., 2016) and soybean oil with phospholipases A1 and C (Jiang et al., 2014).

But it is known that non-hydratable phospholipids contain phosphatidic acids and their salts as well as other salts and complexes with metal ions (O'Brien, 2004). After water degumming oil will contain non-hydratable phospholipids and substantially metal ions such as only hydratable phospholipids are removed. In turn, metal ions, especially Cu^{2+}, Fe^{3+} can promote fatty acid oxidation and increase peroxide content. We suggest, that removing all phospholipids by enzymatic degumming resulted in the higher oxidation stability and low peroxide value of sunflower oil.

Oxidative stability also depends on the antioxidant capacity of oil. The antioxidative properties of sunflower oil samples were 30-36% of scavenged DPPH radical (Figure 6).

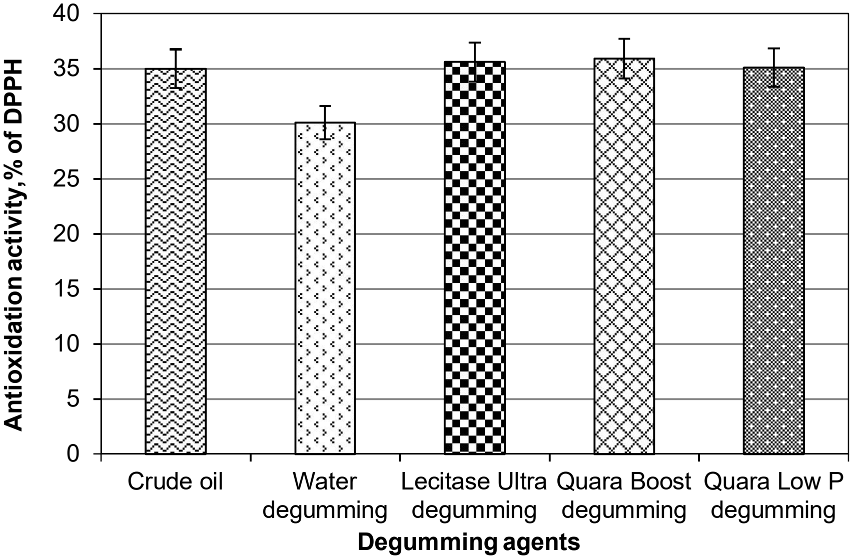

Figure 6. Effect of enzymatic degumming on antioxidant capacity of sunflower oil

The oil sample after Quara® Boost degumming had a slightly higher radical scavenging capacity, which was about 36%. On the contrary, the oil sample after water degumming had the lowest, 30%, radical scavenging capacity. Probably, this radical scavenging capacity decrease was due to the loose of some antioxidants in gums as a result of oil emulsification.

Conclusions

1. Enzymatic degumming is a highly effective tool for removing phospholipids from sunflower oil. The most effective enzyme preparation for degumming sunflower oil is Quara® Boost, which has phospholipase C activity. Quara® Boost degumming results in the highest increase of oil yield, the lowest phospholipid content (16 mg/kg phosphorus), and free fatty acids content, low peroxide value, and high antioxidant capacity of oil.
2. Lecitase® Ultra degumming of sunflower oil resulted in a 1% higher oil yield compared to water degumming, 32 mg phosphorus /kg of oil, the lowest peroxide value, and the high antioxidant capacity of oil. However, this preparation has the disadvantage of significantly increasing the oil acidity. The acid value was increased by three times compared to crude oil.
3. The use of Quara Low P with phospholipase A1 activity for sunflower oil degumming showed lower efficiency with only a 0.5% higher oil yield compared to water degumming. However, the advantages of Quara Low P degumming were a higher degree of phospholipid removal (24 mg phosphorus/kg of oil), a low increase of oil acidity compared to Lecitase® Ultra, high oxidation stability of the oil, as well as thermal stability and low pH optimum of this preparation.

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