24 June 2015
Ref. 15SAF108

MCPD ESTERS AND GLYCIDYL ESTERS

Review of mitigation measures
Revision 2015

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FEDIOL AISBL - THE EU VEGETABLE OIL AND PROTEIN MEAL INDUSTRY
168, avenue de Tervuren (bte 12) ● B 1150 Bruxelles ● Tel (32) 2 771 53 30 ● Fax (32) 2 771 38 17 ● Email : fediol@fediol.eu ● http://www.fediol.eu
Ets n° 0843946520 ● Transparency Register n°85076002321-31

1. Background

In 2007, the presence of esters of 3-monochloropropane-1,2-diol (3-MCPD Esters) was reported in a number of foodstuffs, including refined vegetable oils and fats. Free 3-MCPD was already known as a process contaminant formed during acid hydrolysis of vegetable proteins (including during the production of soya sauce) and a Tolerable Daily Intake (TDI) of 2 μg/kg body weight had been set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). 3-MCPD Esters are compounds formed during the processing and refining of vegetable oils and fats. 3-MCPD Esters have been shown to have a similar toxicological profile as 3-MCPD.

Little is known on toxicological profile of 2-MCPD Esters, but current data show that 2-MCPD Esters are correlated with 3-MCPD Esters. It is anticipated that measures on 3-MCPD Esters will also have the same effects on 2-MCPD Esters.

Glycidyl Esters (GE) are found in all foods that contain refined vegetable oils and fats in their recipes. No regulatory levels have been set.

FEDIOL members have been engaged in research aimed at identifying mitigation practices or technologies to prevent, reduce or remove 3-MCPD Esters and Glycidyl Esters in refined vegetable oils and fats. Over the last two years, this work has given rise to a large number of new processes and practices with beneficial impact on 3-MCPD Esters/Glycidyl Esters formation and to technological process innovations.

2. Purpose and limitations of the document

The purpose of this document is to describe the refining process, identify critical areas with regard to 3-MCPD Esters and Glycidyl Esters formation; and to provide information on credible mitigation techniques known to date and available in published literature for the prevention and reduction of these compounds.

It also lists the existing mitigation techniques which can be applied today, as they are of a practical nature for implementation on an industrial scale.

Refineries differ significantly in their design and processes. Therefore, there is not a 'one-size-fits-all' solution. This document describes a range of mitigation techniques that could be used in combination in order to tailor a refinery-specific solution. Given the various combinations of mitigation techniques which can be applied, it is difficult in practice to give exact figures on the achievable reduction levels.

Depending on the applied methods, the type of raw materials, the types of oils and fats, the type of factory and whether 3-MCPD Esters or Glycidyl Esters are present, different levels of reduction can result from the application of the mitigation measures mentioned here. However, their applicability has to be balanced with other factors and limitations as also described in this document.

3-MCPD Esters and GE mitigation continues to be a high priority for the industry; accordingly, new techniques continue to be developed. Therefore, this document will require periodic review and update to ensure it reflects the latest developments in this area.

3. Formation of 3-MCPD Esters (3-MCPDE) and Glycidyl Esters (GE)

3-MCPD Esters are compounds formed during the processing and refining of vegetable oils and fats. Their occurrence in foods and food ingredients received a particular attention in 2007. They have especially been found in refined vegetable oils and fats, and manufactured products containing such oils and fats.

Glycidyl Esters are another class of compound formed during the processing and refining of vegetable oils and fats. They are found in all foods that contain refined vegetable oils and fats in their recipes.

Progress has been made to identify the exact formation mechanisms of 3-MCPD Esters and Glycidyl Esters in order ultimately to identify the most appropriate mitigation measures. However, further work is still required since different conditions and criteria seem to interact.

Experience built over past years suggests that mitigation of 3-MCPD Esters should focus on the elimination of their precursors, e.g. chlorinated compounds, prior to deodorization step, while mitigation of Glycidyl Esters offers a wider range of effective options, prior, during or post deodorization.

4. Methods of Analysis

In recent years, huge efforts have been made in developing and assessing analytical methodologies for the detection and measurement of 3-MCPD Esters and Glycidyl Esters in vegetable oils and fats in order to find appropriate and reliable analytical techniques. As a result of this intensive effort, three indirect methods developed by the German Society of Oils and Fats (DGF)[1], SGS[2] and Unilever[3] have been available since 2013 for the analysis of 3-MCPD Esters and Glycidyl Esters in vegetable oils and fats. These methods perform well as recently demonstrated by the inter-laboratory comparison study organized by the Joint Research Center (JRC)/ Institute for Reference Materials and Measurements (IRMM)[4] and by the international collaborative study conducted by the American Oil Chemists Society (AOCS). Based on the latter study, these three methods have been adopted as AOCS Official Methods[5].

So far, the only validated available methods, as described above, are based on *indirect* assessment of 3-MCPD Esters and Glycidyl Esters (indirect methods). In practice, indirect methods mean that the esters are quantified after their conversion to the free form and reported as the sum of 3-MCPD or glycidol. Direct methods mean that the individual esters are quantified without any chemical transformation.

For more complex food products, the Joint Research Center (JRC) developed methods for the analysis of MCPD (both in free and esters form) and Glycidyl Esters in various food matrices, details of which were published in March 2015[6].

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[1] DGF Standard Methods, C-VI 18 (10).
[2] Kuhlmann, Eur. J. Lipid Sci. Technol. 113, 335-344 (2011).
[3] Ermacora & Hrncirik, J. Am. Oil. Chem. Soc., 90, 1-8 (2013).
[4] https://ec.europa.eu/jrc/sites/default/files/eur_24356_en_3-mpcd_esters_in_edible_oil.pdf
[5] http://www.aocs.org/Resources/content.cfm?ItemNumber=1011
[6] Thomas Wenzl, Vasilios Samaras, Anupam Giri, Gerhard Buttinger, Lubomir Karasek, Zuzana Zelinkova, 2015. Development and validation of analytical methods for the analysis of 3-MCPD (both in free and ester form) and glycidyl esters in various food matrices and performance of an ad-hoc survey on specific food groups in support to a scientific opinion on comprehensive risk assessment on the presence of 3-MCPD and glycidyl esters in food. EFSA supporting publication 2015: EN-779, 78 pp.

5. Vegetable Oil and Fat Refining in Europe: a Snapshot

In 2012 Europe's vegetable oil and fat refining industry processed about 7 million tons of crude vegetable oils from oilseeds that were crushed in Europe, essentially rapeseed, sunflower seed and soybeans (so called "soft oils").

Furthermore, nearly 6 million tons of crude tropical oils, including palm oil, palm kernel oil and coconut oil, were also refined in European based refineries.

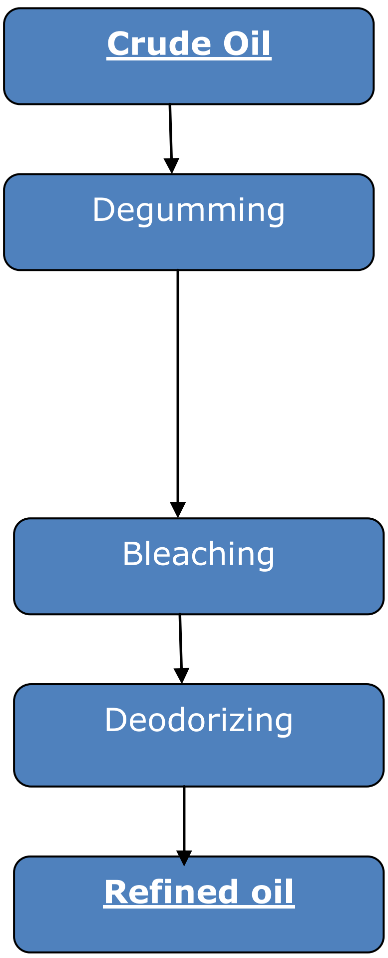
Throughout Europe, we estimate that there are about 100 plants, owned by approximately 60 companies, which are refining "soft oils" and/or tropical oils. The vegetable oil and fat refining sector is relatively concentrated and the number of players is limited.

At EU level, the sector is represented by FEDIOL and the association captures about 90% of the refining volume.

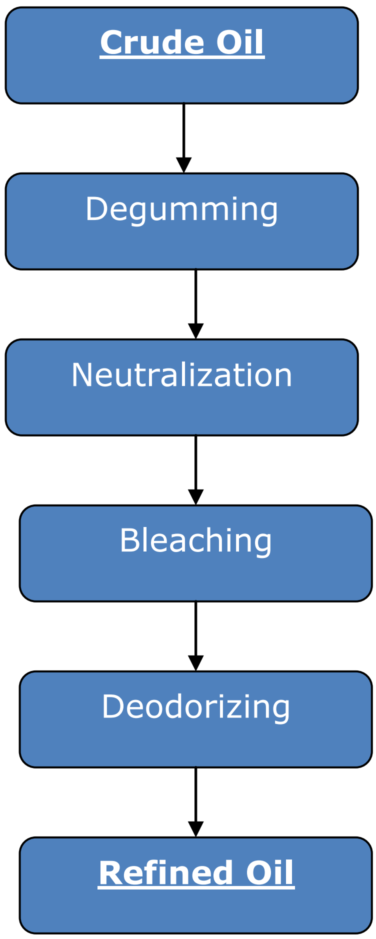
6. Refining Processes

6.a. Flowcharts

Physical Refining



Chemical Refining



6.b. Refining Process: Step Description

Step	Process Description – Refining
Crude Feedstock	There is a wide variety of seed, nut and fruit oils and fats that are refined to produce bland, odourless, fit-for-purpose products that meet both customer and food safety and quality requirements. Tropical oils have a tendency to have higher Free Fatty Acid and very low phospholipid content. It should be noted that FFA can be minimised by rapid sterilisation of the fruits, for example for palm. By contrast, seed oils tend to contain lower levels of FFA, but higher contents of phosphatides (gums) than tropical oils. It has become clear that different oils and fats vary in their potential to form both 3-MCPD Esters and GE, depending not only on the raw material but also the processing conditions applied to produce such oils/fats.
Degumming	Removal of phospholipids after the addition of both water (water-soluble phospholipids removal) and acids (non-hydratable phospholipids removal) followed by centrifuging off the gums (phospholipids) from the oil.
Neutralization (Chemical Refining)	This process is mainly applied to seed oils, which have a tendency towards lower Free Fatty Acid content and relatively higher levels of phospholipids. The process involves the neutralisation of the Free Fatty Acids by reaction with a chemical such as caustic soda forming soap and the subsequent removal of the soap, most notably by centrifugal separation and water washing. This process is not very common for tropical oils.
Dry Degumming (Tropical Oils)	In the case of crude oils with very low amounts of gums, the classic degumming process with centrifugation cannot be applied. Therefore, for tropical oils, the removal of phospholipids is done after adding acid, which is then removed during the subsequent bleaching step.
Bleaching	Removal of colouring pigments, residual phospholipids, residual soap, metals, etc; through the addition of adsorbent bleaching clay and the subsequent removal of the clay by filtration.
Deodorization (Chemical Refining)	Steam distillation process, to remove odour and taste-bearing volatiles, reduce the colour and remove volatile contaminants, where the pre-treated oil is heated to temperatures typically between 220°C and 250°C, whilst steam is injected into the oil/fat under vacuum.
Deodorization (Physical Refining)	Deodorization is a steam distillation process, but unlike chemical refining, Free Fatty Acids are removed at this stage to meet the refined oil specification limits, which are typically <0.1%. Apart from FFA evaporation the aim is to remove odour and taste-bearing volatiles, reduce the colour and remove volatile contaminants. The pre-treated oil is heated to temperatures typically between 230°C and 270°C, whilst steam is injected into the oil/fat under vacuum. High FFA oils like tropical oils usually require temperatures of the higher end of the above range or a longer retention time at lower temperatures.

6.c Fat modification Process: Step Description

Step	Process Description – Fat Modification
Chemical Interesterification	Re-arrangement of the fatty acids on the glycerol molecule. This re-arrangement alters the functional behaviour of the oils/fats.
Enzymatic Interesterification	Re-arrangement of the fatty acids on the glycerol molecule using an enzyme. This re-arrangement alters the functional behaviour of the oils/fats.
Hydrogenation	Partial or full conversion of unsaturated fatty acids into saturated fatty acids with hydrogen, increasing the melting point and solid fat content of the oil/fat.
Fractionation	Physical separation of the triglycerides into a high- and a low melting fraction by cooling and crystallisation and the subsequent filtration of the crystallised portions (high melting = ‘ stearine’) and non-crystallised portions (low melting = ‘olein’).

7. Towards Mitigation Measures within the Refining Processes

7.a Mitigation: Measures Applicable to 3-MCPD Esters

Quality of Crude Feedstock

	Mitigation Possibilities	Limitations
Free Fatty Acid	It has been demonstrated that a low FFA level in the starting material generally has a beneficial effect on the level of 3-MCPD Esters formed during the subsequent refining processes. One reason is the potential to deodorise at lower temperatures as there is less FFA to remove. It should be noted that longer retention times may also be able to remove FFA at lower deodorization temperatures.	- For tropical oils, low FFA material (<1.5%) is both difficult to source and cost-inefficient. - If shipped from the tropics to the EU, the FFA level may rise during shipment. A low FFA alone may not reach 3-MCPD Esters levels required and therefore may need to be combined with additional mitigation, such as chemical refining. - Concerning seed oils, seeds are stored after harvest and processed through the campaign. During storage the FFA of the oil noticeably increase (hydrolysis). - The FFA of crude seed oil is strongly influenced by weather conditions, which can result in high FFA (>1,5%) crops.
Chlorine	Presence of (most likely organic) chlorine precursors that contribute to 3-MCPD Esters formation are of course an important factor. It is speculated that a proportion of the precursors are water soluble and therefore can be removed during water washing/caustic refining (see below).	However, these precursors have not to date been successfully identified in crude feedstock and cannot be monitored.

Water Washing

	Mitigation Possibilities	Limitations
Water washing	It has been demonstrated on tropical oils that washing vegetable oils/fats prior to refining can reduce 3-MCPD Esters formation significantly. It is suspected that the level of chlorine precursors is reduced during this process. Water washing is generally included in neutralization. In physical refining the full degumming step is sometimes followed by water washing for further gums removal.	- Water washing requires the refining plant to have centrifugal separation techniques, which is not common for tropical oil refining. - Relatively high levels of water are required, having an environmental impact. - Yield is reduced due to oil loss during washing. - However it should be noted that water washing appears to have more impact when carried out at origin, water washing post shipment to Europe seems to be less effective.

3-MCPD Esters

Degumming (Acid)

	Mitigation Possibilities	Limitations
Acid Degumming	Use of milder and less acid during degumming may decrease 3-MCPD Esters formation during the deodorization process.	Whilst acid addition may be minimized/optimized it is essential that phospholipid (gums) are still removed during the de-gumming process, otherwise other quality parameters such as colour, taste, stability, may be negatively impacted.

Degumming (Dry)

	Mitigation Possibilities	Limitations
Dry Degumming	No substantial effect reported	NA

Neutralization (Chemical Refining)

	Mitigation Possibilities	Limitations
Chemical Refining Precursors	- It has been demonstrated that chemical refining results in lower 3-MCPD Esters levels in fully refined oils and fats. - Neutralization is generally combined with one or two water washing steps to remove soaps, which is advantageous in the minimization of 3-MCPD Esters content. - It is believed that there is a chlorine precursor reduction during this process step. Additionally as the FFA is neutralised via the caustic refining, the deodorization temperature can be significantly lower than that for physical refining.	Tropical oils: - They are generally physically refined and these plants normally do not have the equipment to run chemical refining process. - The yield from chemical refining of high FFA tropical oils is lower than from the physical process. - Implementation of a chemical refining process for tropical oils/fats would in all probability be commercially unviable. - Additionally, the use of chemical refining for tropical oils would result in high levels of soap-stock and subsequent environmentally undesirable post processing. Seed oils: - Chemical refining is not a viable option for existing physical refineries due to yield, soap-stock handling and environmental and commercial implications.

3-MCPD Esters

Bleaching

	Mitigation Possibilities	Limitations
Bleaching Earths	The use of neutral bleaching clays is a potential tool to reduce levels of 3-MCPD Esters in fully refined vegetable oils/fats.	- Neutral bleaching clays can have a negative effect on the final product quality in relation to colour, flavour and stability (shelf-life). Additionally, the use of neutral bleaching clays is also somewhat dependent on feedstock quality. - In the case of seed oils with significant chlorophyll content (especially rapeseed oil), neutral clays do not provide sufficient chlorophyll removal, and so acid activated clays are used.

Deodorization (Physical Refining)

	Mitigation Possibilities	Limitations
Temperature	Whilst 3-MCPD Esters can form at relatively low temperatures (<150°C), minimising temperature will have some impact in reducing 3-MCPD Esters levels.	- Distillative removal of high amount of FFA needs temperatures up to 250 and 270°C or extended retention times in the case of seed oils and tropical oils respectively. - Temperature forms part of Food Safety and a minimum temperature is required to ensure that other potential volatile contaminants, e.g. pesticides, PAH, are safely removed. - In order to achieve acceptable organoleptic properties, a minimum temperature profile is also required. - Lower deodorization temperature needs to be validated to ensure all quality parameters in refined product are met. .
Vacuum	- Better vacuum facilitates the evaporation of undesirable components, therefore helps in reducing temperature. In this indirect way it contributes to 3-MCPD Esters reduction.	- The best reasonably available vacuum in physical refining is 1-2 mbar.

3-MCPD Esters

Deodorization (Chemical Refining)

	Mitigation Possibilities	Limitations
Temperature	- Removing the Free Fatty Acids during neutralization results in a potential reduction in the deodorization temperature (see the typical temperature ranges in section 6). - Reduced temperatures tend to result in lower 3-MCPD Esters levels.	- Temperature forms part of Food Safety requirements and a minimum temperature is required to ensure that other potential volatile contaminants, e.g. pesticides and PAH, are safely removed. - Additionally, in order to achieve acceptable organoleptic properties, a minimum temperature profile is also required. - Lower deodorization temperature needs to be validated to ensure all quality parameters in refined product are met.
Vacuum	- Better vacuum facilitates the evaporation of undesirable components, therefore helps in reducing temperature. In this indirect way it contributes to 3-MCPD Esters reduction.	- In chemical refineries the deodorizer is operated at not lower than 3 mbar as there is no need for FFA removal.

Chemical Interesterification

	Mitigation Possibilities	Limitations
Chemical Interesterification (CIE)	Chemical interesterification (CIE) can substantially reduce the level of 3-MCPD Esters.	- CIE can have a substantial effect on the functionality of a fat, so has a limited potential for 3-MCPD Esters reduction. - As there is still a potential to create further 3-MCPD Esters downstream, care must be taken in further processing so as not to re-introduce it.

Enzymatic Interesterification

	Mitigation Possibilities	Limitations
Enzymatic Interesterification	No substantial effect reported	NA

3-MCPD Esters

Hydrogenation

	Mitigation Possibilities	Limitations
Hydrogenation	No substantial effect reported	NA

Fractionation

	Mitigation Possibilities	Limitations
Fractionation	This process concentrates 3-MCPD Esters in the more liquid phase, so for harder fractions there is a reduced 3-MCPD Esters level compared to the starting oil/fat.	Conversely, higher levels of 3-MCPD Esters are found in the softer/liquid fraction.

7.b Mitigation: Measures Applicable to Glycidyl Esters

Quality of Crude Feedstock

	Mitigation Possibilities	Limitations
Free Fatty Acid/ Diacylglycerides (DAG)	- Diacylglycerides (DAG) are one of the precursors to GE formation. Minimizing the hydrolytical reactions in the whole supply chain and reducing the levels of DAG have a potential lowering effect on GE formation during deodorization. - Generally FFA can be used as a simple but not definitive marker of DAG levels.	- For tropical oils low FFA material (<1.5%) is difficult and expensive to source. - If shipped from the tropics to the EU then the FFA level may rise during shipment - Reducing DAG alone will not help to achieve low GE levels. It has to be used in combination with other techniques. - For seeds oils, seeds are stored after harvest and processed through the campaign. During storage the FFA of the oil noticeably increase (hydrolysis). - The FFA level of crude seed oil is strongly influenced by weather conditions, which can result in high FFA (>1,5%) crops.

Neutralization (Chemical Refining)

	Mitigation Possibilities	Limitations
Neutralization (Chemical Refining)	- Removing the Free Fatty Acids during chemical refining results in a possibility of reduced temperature requirement during the subsequent deodorization process, as this higher temperature is not required for Free Fatty Acid removal. - Higher deodorization temperatures, typically in excess of 230°C are known to result in a significant exponential increase in Glycidyl Esters formation.	Tropical oils: - They are generally physically refined and these plants normally do not have the equipment to run chemical refining process. - The yield from chemical refining of high FFA tropical oils is lower than from the physical process. - Implementation of a chemical refining process for tropical oils/fats would in all probability be commercially unviable. - Additionally, the use of chemical refining for tropical oils would result in high levels of soap-stock and subsequent environmentally undesirable post processing. Seed oils: - Chemical refining is not a viable option for most existing physical refineries due to yield, soap-stock handling and from an environmental and commercial point of view.

Glycidyl Esters

Degumming (Dry)

	Mitigation Possibilities	Limitations
Water or Acid Degumming	No substantial effect reported	NA

Bleaching

	Mitigation Possibilities	Limitations
Bleaching	No substantial effect reported	NA

Deodorization (Physical Refining)

	Mitigation Possibilities	Limitations
Temperature	- Glycidyl Esters are mainly produced at temperatures higher than 230 °C; their levels increase exponentially with deodorization temperatures above 230°C. - This process can be optimised by minimising deodorization temperatures to produce material with lower GE levels. Temperatures can to a certain extent be lowered at the expense of longer deodoriser retention times.	- Distillative removal of high amount of FFA needs temperatures up to 250 and 270°C in the case of seed oils and tropical oils respectively, although longer deodoriser retention times can partially compensate. - Temperature forms part of Food Safety requirements and a minimum temperature is required to ensure that other potential volatile contaminants, e.g. pesticides and PAH, are safely removed. - In order to achieve acceptable organoleptic properties, a minimum temperature profile is also required. - Lower deodorization temperature needs to be validated to ensure all quality parameters in refined product are met.
Vacuum	- Better vacuum facilitates the evaporation of undesirable components, therefore helps in reducing temperature. In this indirect way it contributes to Glycidyl Esters reduction.	- The best reasonably available vacuum in physical refining is 1-2 mbar.

Glycidyl Esters

Deodorization (Chemical Refining)

	Mitigation Possibilities	Limitations
Temperature	- Glycidyl Esters are mainly produced at temperatures higher than 230°C; their levels increase exponentially with deodorization temperature. - This process can be optimised by minimising deodorization temperatures to produce material with lower GE levels. - Removing the Free Fatty Acids during neutralization results in a potential reduction in the deodorization temperature (see the typical temperature ranges in section 6).	- Temperature forms part of Food Safety requirements and a minimum temperature is required to ensure that other potential contaminants, e.g. pesticides and PAH, are safely removed. - Additionally, in order to achieve acceptable organoleptic properties, a minimum temperature profile is also required. - Lower deodorization temperature needs to be validated to ensure all quality parameters in refined product are met.
Vacuum	- Better vacuum facilitates the evaporation of undesirable components, therefore helps in reducing temperature. In this indirect way it contributes to Glycidyl Esters reduction.	- In chemical refineries the deodorizer is operated at lower vacuums (higher mbar number) as there is no need for FFA removal.

Chemical Interesterification

	Mitigation Possibilities	Limitations
Chemical Interesterification (CIE)	- GE can be reduced via this route but only as a consequence of the need to bleach post CIE. In fact CIE will increase GE significantly, but bleaching step post CIE (applying acid activated bleaching earth and the right parameters and process) will remove virtually all GE.	- CIE can have a substantial effect on the functionality of a fat, so has a limited potential. As there is still a potential to create further GE downstream, care must be taken in further processing so as not to re-introduce it; limit deodorization temperature.

Enzymatic Interesterification

	Mitigation Possibilities	Limitations
Enzymatic Interesterification	No substantial effect reported	NA

Glycidyl Esters

Hydrogenation

	Mitigation Possibilities	Limitations
Hydrogenation	No substantial effect reported	NA

Fractionation

	Mitigation possibilities	Limitations
Fractionation	This process concentrates Glycidyl Esters in the more liquid phase, so for harder fractions there is a reduced GE level	Conversely there is an increase in GE levels in the softer/liquid fraction.

Post-Refining

	Mitigation Possibilities	Limitations
Re-bleaching	- Similar to the bleaching step after chemical interesterification, re-bleaching of deodorized oil removes significant quantities of Glycidyl Esters. Acidic clays are proposed. - Contacting the 'regular' deodorised oil with an absorbent (e.g. bleaching clays, various silicates etc.) under regular bleaching conditions, but at adsorbent levels that can deviate from conventional bleaching	- Significant plant capacity loss as oil/fat also has to be re-deodorised due to flavour taint from bleaching earth. Even though the process will remove virtually all the Glycidyl Esters the re-deodorization process can produce Glycidyl Esters again; so care must be taken to keep the re-deodorization temperature below 230^{o}C
Re-deodorization	Re-deodorization at temperatures below 230^{o} C where increase of the GE levels is minimal	- As above

7.c Notes

- The tools and technologies for lowering quantities of both 3-MCPD Esters and Glycidyl Esters mentioned in this document may be covered by Intellectual Property Rights either as patent applications or actual granted patents.
- FEDIOL members have expressed their willingness to share knowledge and access to the use of these technologies on reasonable terms.

8. Other measures after the Refining

Application of oils

	Mitigation Possibilities	Limitations
Selection of oils	Through the selection of oils/ fats or blends thereof that naturally contain or contain mitigated lower levels of 3-MCPD Esters or GE, the levels could be lowered in the finished product. The same approach can be applied to precursors.	Changes in solidness, texture, stability or other technological properties could occur
Reduction of fat content in recipe	As 3-MCPD Esters and GE are almost exclusively contained in refined oils and fats, a reduction of fat in the finished product will also reduce the overall 3-MCPD Esters and GE-levels	Only limited applications are possible. Lowering the fat content will change the product and its taste etc. Also the processability of the product will be influenced.
Reduction of process temperatures	High temperatures can accelerate the formation of 3-MCPD Esters and GE	- This is only applicable for processes that bear a potential for the formation of 3-MCPD Esters and GE. - Reduced temperature might make changes in the process length necessary. Also changes in the sensory profile might occur. - Reducing temperatures can generate product safety issues (microbiology, removal of unwanted compounds…).
Frying fats should be used for as short a time as possible.	High temperatures can accelerate the formation of 3-MCPD Esters and GE (3-MCPD Esters already form at >150°C)	Cannot be used in continuous processes, only in batch processes. Shorter usage of frying fat will generate additional costs.

As regards further food processing, there is indication, albeit limited, that some factors - such as reducing salt; reducing temperature during the frying or during the cooking process; or frying/cooking fats for as short a time as possible - could be tools to prevent and/or reduce MCPDE Esters occurrence. Further research is needed. However, this implies other sectors downstream to devise and set mitigation measures for these stages.

9. Conclusions

The FEDIOL review of existing mitigation measures gives an overview of currently available techniques that can be applied at different stages of the refining process. It is the responsibility of the EU vegetable oil and fat industry to elaborate and implement at facility level the most effective combination of mitigation approaches. This review therefore focuses on the refining process.

It demonstrates that a variety of measures can be taken today, which have the potential to reduce MCPD Esters and Glycidyl Esters. It also shows that there is no one-size-fits-all technique, nor any breakthrough technology. Instead, what currently needs to be implemented is a combination of techniques, taking into account the type of oil, the refining parameters and the specificities of each factory. The review also identifies some measures after refining which could be considered downstream for mitigation work.

FEDIOL members are committed to further research in this area to improve available techniques.

This document will be regularly updated to take into account future developments.