Prioritisation report for nutritional improvement of rapeseed oil

Ian Bancroft and Roxana Teodor, University of York, 17th May 2019

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Ian Bancroft and Roxana Teodor, University of York, 12th April 2019

Industry requirements

The industry need to improve the nutritional value and cooking, processing and storage properties of oil from oilseed rape was evaluated via surveys and interviews conducted by ADAS and Campden BRI, with input from the British Nutrition Foundation (reports appended). Key quality parameters investigated included those relevant to health and/or oil properties, including content of vitamin E, vitamin K, phytosterols and oxidative stability (largely controlled by the levels of saturated, unsaturated and polyunsaturated fatty acids). In addition to a preference expressed for local (UK) production, and as a more sustainable alternative to palm oil, the key conclusions of the analysis are that the main industry drivers are:

1. Fitness for purpose
Rapeseed oil must possess the physical and chemical properties required for the purposes to which it is being put by industry. Rapeseed oil does not contain a sufficiently high proportion of saturated fatty acids for applications such as use in puff pastry, but does have the properties for a wide range of food processing applications. The main limitation is oxidative stability, which limits both shelf life and suitability for high temperature frying.

2. Perceived health benefits
Rapeseed oil is widely perceived as a healthy choice of oil, primarily due to its low content of saturated fatty acids (the lowest of all standard fats and vegetable oils) and high content of unsaturated fats, including long-chain omega-3 polyunsaturated fatty acids. It is also recognised that rapeseed oil contains fat-soluble compounds with health benefits, including phytosterols (which reduce the absorption of unhealthy cholesterol), vitamin K (which builds strong bones and promotes the synthesis of an amino acid involved in blood clotting) and vitamin E (which protect humans from oxidative stress, atherosclerosis, cardiovascular diseases, cataracts and neural tube defects). The main limitations are the amount and variability of these fat-soluble compounds in commercially available rapeseed oil.

Opportunities for genetic improvement of nutritional traits

The OREGIN genetic diversity panel *Brassica napus* accessions (the species to which oilseed rape belongs as a crop type) has already been assesses for most of the traits of relevance and found to contain genetic variation for them all. The primary publication of the resource, comprising 383 accessions, showed tocopherol (vitamin E) varied between 197 and 445 mg/kg dry seed and in food grade (i.e. low erucic acid) material that saturated fatty acids (SAFA) varied between 5.43 and 8.70 % and polyunsaturated fatty acids (PUFAs) varied between 19.6 and 38.6% (Havlickova et al. Plant Journal 93:181-192, 2018). Unpublished results showed phytosterols to vary between 1722 and 3992 mg/kg dry seed, with scope to double this by traditional mutagenesis (Broughton et al, unpublished). Vitamin K has not been analysed on OREGIN material, but a recently published assessment across 7 varieties showed 3-fold variation (Claussen et al. J. Agric. Food Chem. 63: 1076-1081, 2015) indicating that substantial genetic variation is likely to be available.

Breeders have already been working on improving the oxidative stability of rapeseed oil by developing high oleic low linolenic (HOLL) types. However, these do not satisfy the industry's requirements, so there is scope for further improvement. Work towards an alternative oil specification, high oleic low

polyunsaturate (HOLP), is yielding promising results with higher unsaturated fatty acid content, lower saturated fatted acid content (Wells et al. Molecular Breeding 33:349-362, 2014) and substantially better thermal stability (Kaur et al unpublished).

The analyses reveal there to be extensive scope for improving the nutritional quality of rapeseed oil. Priority traits identified are phytosterol, vitamin E and vitamin K content, all of which have been shown (or are expected to show) variation in germplasm available to OREGIN. Part of the variability observed for these compounds in rapeseed oil is considered to be due to processing (especially deodorization), so processing options such as removal and reincorporation may also need to be evaluated in order to preserve customer's expectation of oil appearance whilst enhancing content.

Prioritisation for rapeseed nutritional improvement

Combining nutritional and stability traits would be most compelling commercially. Pre-breeding assessment by combining nutritional improvements in the HOLP background would benefit from freedom to operate and facilitate subsequent transfer by breeders to proprietary backgrounds tailored for the UK market.

Prioritisation of activities:

1. Maximise phytosterol content in a HOLP winter oilseed rape background. This represents the greatest potential health-based gain, as we project it may be possible to reach the 0.8g per day necessary to make a health claim for a daily intake of 20 ml of oil, with that oil also being very high in unsaturates (up to 90%).

2. Maximise vitamin E content in a HOLP winter oilseed rape background. This represents the greatest potential product stability-based gain, as vitamin E is an antioxidant that will contribute to oil stability as well has having nutritional value.

3. Assess vitamin K content across the OREGIN *B. napus* genetic diversity panel and evaluate opportunities for future improvement. This is a prerequisite for focused investment in improvement.

We anticipate that further activities will involve processors to enable us to make oil samples available for the food industry for testing, a UK specialist supply chain management company to assemble a supply chain based on pre-breeding products and UK rapeseed breeders to initiate development of new elite varieties for cultivation in the UK.

Acknowledgements

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Report on:

2017 Viewpoints on the use, benefits and perceived nutritional quality of Rapeseed Oil Survey

Work performed by Campden BRI (Chipping Campden) Limited
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Introduction:

Rapeseed oil is the third largest source of vegetable oil in the world and the third largest crop in terms of land coverage grown in the UK the first being wheat and the second being barley.
Rape is produced from black seeds of the rape crop and is a member of the brassica family (*Brassica napus)*, including mustards, Brussel sprouts, kale, cabbage, cauliflower and broccoli. The most common usage for rapeseed oil is as a biofuel, in animal feeds and as vegetable oil.
Amongst its many properties, it is rich in omega 3,6 and 9 oils, vitamin K, and it has a high smoke point making it an ideal for frying. Rapeseed oil is lower than olive oil in both saturated monosaturated fats and it has a very delicate earthy, nutty flavour that does not bleed out during cooking. However, public perception of the oil is often as that of an inexpensive, low-quality product with a bitter taste that is pressed using heat and chemicals.

Rapeseed oil is the only oil commonly used for food production which can be both grown and processed in the UK, having been heralded as the “British Olive Oil”. It is also widely grown in other countries such as Ireland, France, Germany, Netherlands and Canada.

This oil is versatile and relatively inexpensive to produce and as such makes it an ideal candidate for a scope for improvement. For example, improvement in flavour through cold pressing, driven by UK farmers spotting a gap in the market for a “High Quality” rapeseed oil.

Industry and the public are increasingly interested in oils that can have improved benefits such as improved nutritional content, flavours and versatility. Therefore, the need for further research to establish how rapeseed oil can be improved would prove very beneficial.

Aim:

Conduct a survey to assist The University of York in establishing whether there is enough interest in the nutritional benefits of rapeseed oil to warrant further research projects on this topic. The results from the survey will help to justify future research programmes for improving specific traits of oilseed rape, resulting in a better oil for human consumption.

Assess the most important oil qualities for the relevant industries and whether traits that we already know of (such as the content of tocopherols, phytosterols etc) would be of interest to the relevant industry stakeholders of the UK market.

Methodology:

An industrial survey was generated and distributed via survey monkey to the rapeseed oil supply chain. The survey questions were determined through consultation with The University of York, Campden BRI and ADAS. The survey was constructed to obtain a fair, holistic answer to the main question: ‘is there is sufficient interest in the nutritional benefits of rapeseed oil to warrant a future research programme for improving specific traits in oilseed rape, that would result in a better oil for human consumption?’

The survey was distributed to a wide business sector to enhance the chances of a good response rate from relevant people who take an interest in the rapeseed oil supply chain. The survey was distributed using the following means:

- Campden BRI Newsfeed which reaches approximately 6,600 people
- LinkedIn – Campden BRI has 6,000 followers
- Included in the Campden BRI newsletter – currently, have 1,500 print and 13,500 in the e-newsletter

Survey Questions:

Q1: What is the name of your business? (optional Question)

Q2: Please indicate the approximate size of your business

Q3: In which sector of the industry is your business? (please select from the list)

Q4: What are the primary oils you use in your production?

Q5: Does your business use rapeseed oil? If not, what is preventing you from using rapeseed oil?

Q6: If rapeseed oil had the following positive physical properties how would you rank these features in order of importance. (1 being very important and 10 is not important)

Q7: If rapeseed oil had, the following positive nutritional properties how would you rank these features in order of importance. (1 being very important and 10 is not important)

Q8: Please state any other important positive physical or nutritional properties of rapeseed oil:

Q9: How do you think consumers perceive rapeseed oil? Please give a reason for your answer.

Q10: Are there any products where you could see rapeseed oil being used more or being used as an alternative to other oils? if yes please state what kind of products.

Q11: Are you willing to be contacted for a short follow up an interview?

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Results:

Q1: What is the name of your business? (optional Question)

Respondent	Company Name
1	Respondent skipped this question
2	Respondent skipped this question
3	Company details provided
4	Respondent skipped this question
5	Company details provided
6	Respondent skipped this question
7	Respondent skipped this question
8	Company details provided
9	Company details provided
10	Respondent skipped this question
11	Company details provided
12	Company details provided
13	Company details provided

Table 1: Company names of respondents
In answer to Q1, 46% of respondents skipped the question. The remaining 54% of respondents provided the name of their company.

Q2: Please indicate the approximate size of your business

Respondent	Company Size
1	Medium-sized (< 250 members of staff)
2	Large (> 250 members of staff)
3	Medium-sized (< 250 members of staff)
4	Small (< 50 members of staff)
5	Medium-sized (< 250 members of staff)
6	Large (> 250 members of staff)
7	Small (< 50 members of staff)
8	Large (> 250 members of staff)
9	Large (> 250 members of staff)
10	Large (> 250 members of staff)
11	Large (> 250 members of staff)
12	Large (> 250 members of staff)
13	Large (> 250 members of staff)

Table 2: Size of the business of respondents

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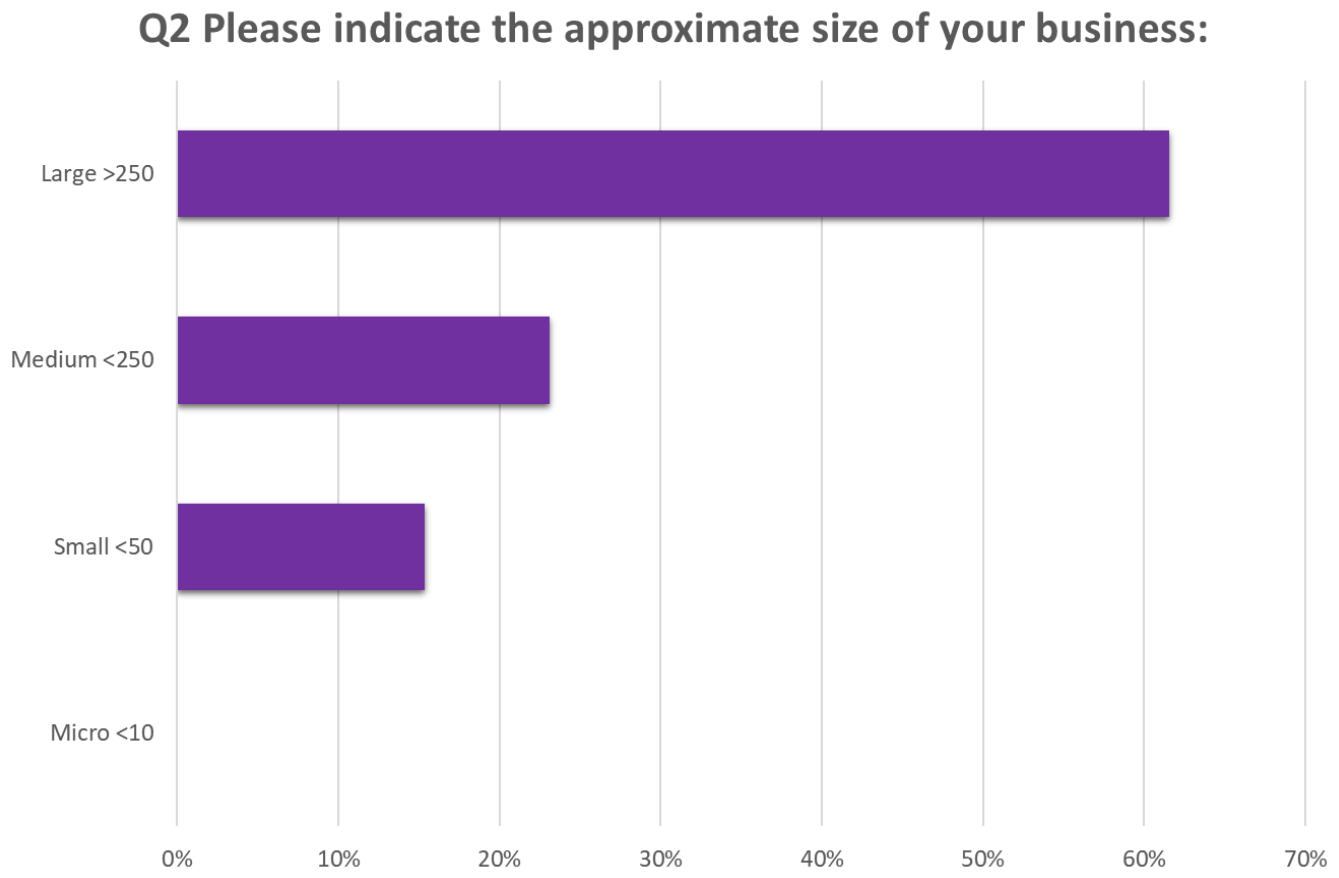

Figure 1: Graphical illustration of the business size of respondents

In reply to Q2 relating to the company size, 61.54% of the respondents answered that they are a large company, 23.08% responded that they were a medium company and the final 15.38% of respondents described themselves as a medium company. None of the respondents described themselves as a small business (<10).

Q3: In which sector of the industry is your business (selected from the list)

Respondent	Industry Type
1	Bakery
2	Other- Retail
3	Fats and Oils
4	Other- Flavours
5	Other-Ready Meals
6	Other- Ingredient Blending
7	Fats and Oils
8	Bakery
9	Bakery/ Foodservice/ Wholesale/ Industrial/ Artisan
10	Fats and Oils
11	Infant and Young Child Nutrition
12	Other-Ingredients
13	Other-Ingredient Supplier

Table 3: Sector of Industry in which respondents

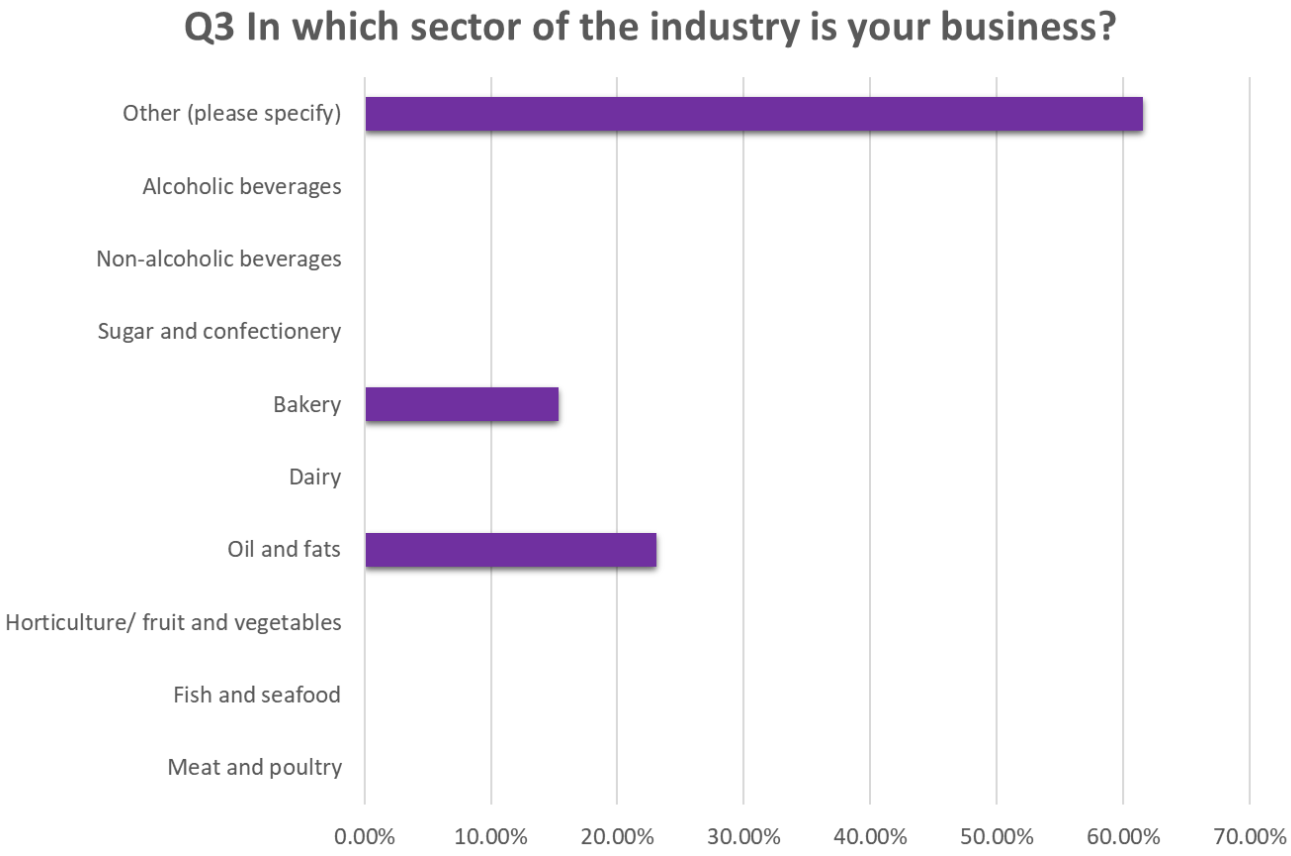

Figure 3: Graphical illustrator of the sector of Industry in which respondents

In answer to Q3, 23.08% of respondents indicated that they are Oil and Fats businesses,15.38% from the bakery industry and the remaining 61.45% answered as “Other”. This section composed of retail, flavour, ready meal production, ingredient blending and ingredient suppliers.

Q4: What are the primary oils you use in your production?

Respondent	Primary Oils used in Production
1	Rapeseed oil, Palm oil, Butter, Coconut
2	Rapeseed oil
3	Sunflower oil
4	n/a
5	Rapeseed oil
6	Rapeseed oil, sunflower oil
7	Refining
8	Rapeseed oil, Sunflower, Palm oil
9	Hardened Palm Kernel Oil, All Palm Blend, Hardened Palm Blend, Rapeseed oil, Sunflower
10	Palm oil, Rapeseed oil
11	Full range of vegetable oils, butter oils and fish oils
12	Palm oil, Rapeseed oil, Sunflower oil, Mineral oil
13	Our customers can use all edible oils and fats

Table 4: Primary oils that respondents use in their production processes

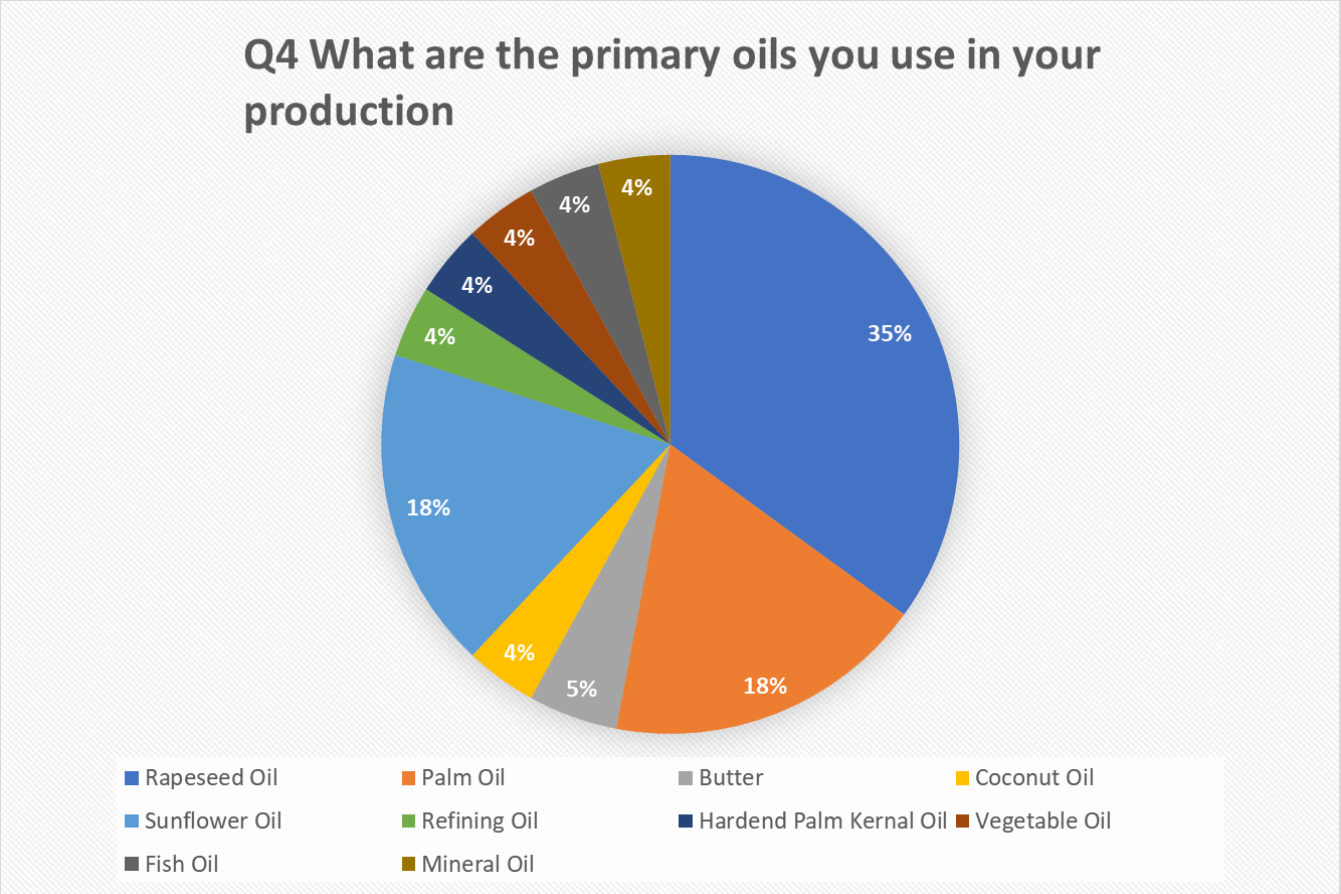

Figure 4: Pie chart illustrating the primary oils used by the respondents

The pie chart above illustrates which oils are used in the respondent's production processes. Rapeseed oil was the most widely used by respondents with 35% of respondents replying that they used this oil. This was followed closely by Palm Oil and Sunflower Oil, both 18% respectively. The remaining fats and oils were less widely used.

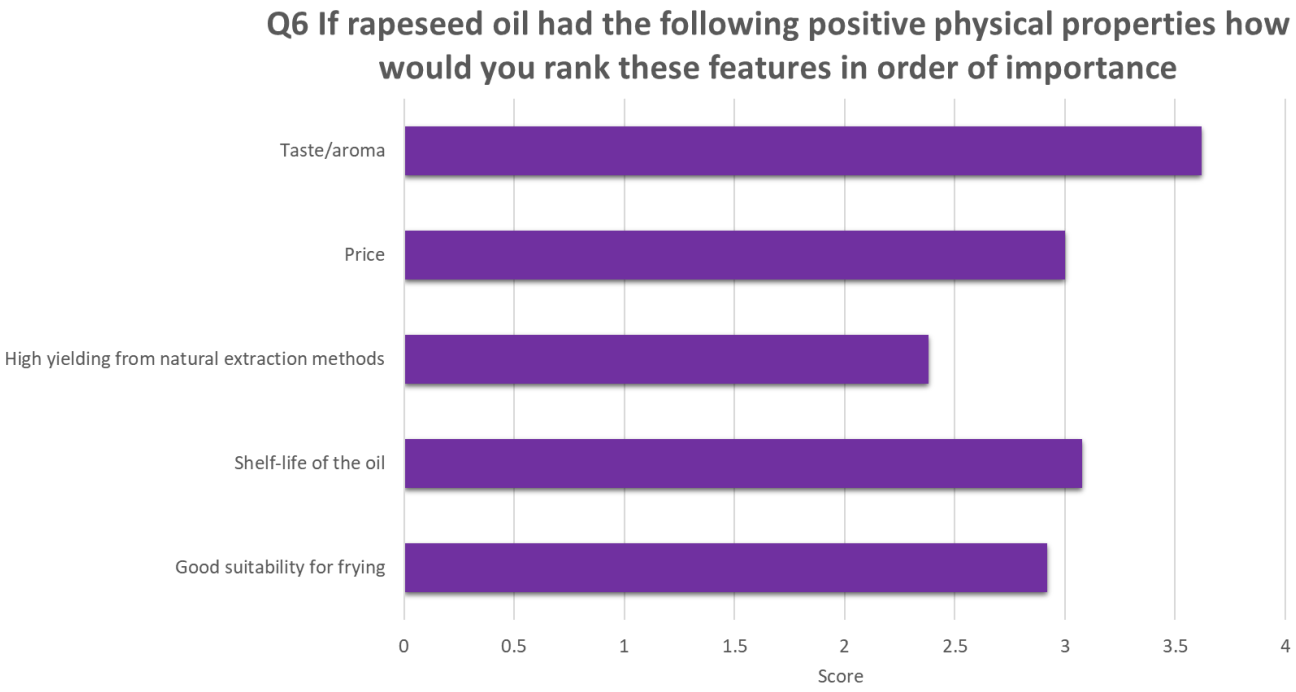

Figure5: Graphical illustration showing the ranking of desirable physical properties

Taste and aroma scored ranked the highest for desirable properties, followed by shelf life, price, frying stability and high yield.

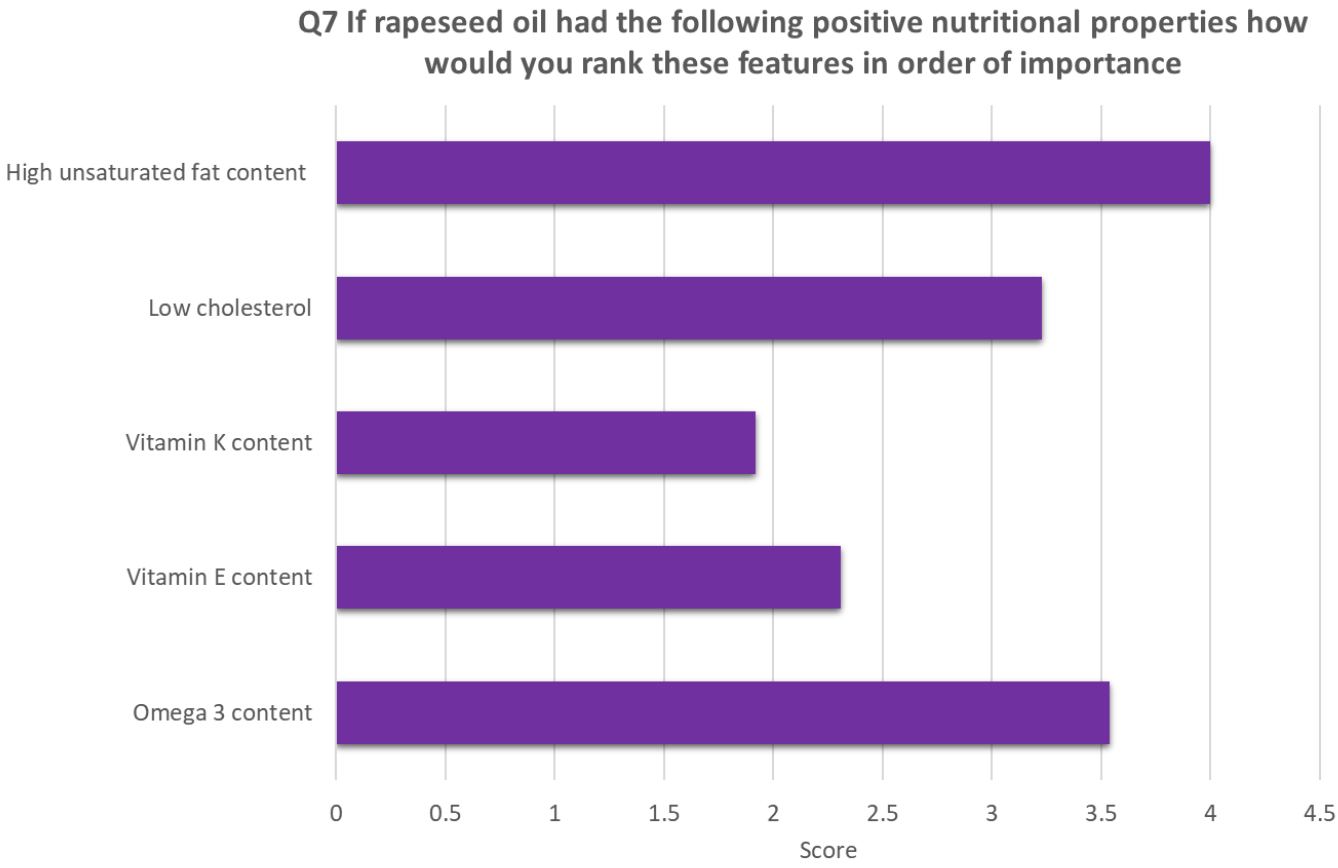

Figure 6: Graphical illustration showing the ranking of desirable oil nutritional properties

When asked to rank the nutritional properties of rapeseed oil, being high in unsaturated fat scored the highest, followed by the omega 3 content, low cholesterol Vitamin E contents and final Vitamin K content.

Q8: Please state any other important positive physical or nutritional properties of rapeseed oil

Respondent	Important Physical or Nutritional Properties
1	Rapeseed oil, Palm oil, Butter, Coconut
2	Physical uses to replace hard fats if this was achievable. Perception (below) would enhance the offering and assist with circular economy/ origin claims. Potential enhancement of nutritional profile to deliver a contribution to diet: Vitamin A/ D/ B2, Iron/ Calcium: there is an increase in younger consumers avoiding the use of fortified products and would prefer naturally higher vitamin and mineral contribution from natural materials. This would be an opportunity to deliver on vitamin/ mineral levels in a commodity material
3	Erucic acid
4	Liquid at room temperature
5	Stability of the oil during frying
6	Clear, bright yellow in colour

Table 5: Other important physical or nutritional properties of rapeseed oil.
Six out of thirteen respondents answered question 8. One of the respondents appeared to have misread the question. From the remaining 5, it is believed that the nutritional content of rapeseed oil can be improved, being liquid at room temperature and its stability during frying where all deemed important qualities.

Q9 How do you think consumers perceive rapeseed oil? Please give a reason for your answer

Respondent	Primary Oils used in Production
1	I would expect customers to see the oil as natural and locally sourced/grown so good for the environment and the local/UK producers. Also, no GMO association at present
2	As a healthy oil
3	Historically as the cheapest "vegetable oil", now there are premium rapeseed oils, so I would expect perception to improve
4	There is very little understanding of the term Vegetable oil and most consumers don't seem to be able to differentiate between oil types
5	More positive over Hardened/ Hard fats due to the nature of the physical state. Increased popularity in green oils, i.e. Cold pressed Rapeseed. However, the latter contributes a flavour which is not ‘clean’ for industrial use
6	Healthy versatile
7	Like the smell and taste of the product
8	Some like that coldest pressed are British, has a high smoke point and has less saturated fat than olive oil but many associates it with the sickly-sweet smell of oilseed rape in flower and that puts them off
9	They only consider it as 'cooking oil' and buy by price
10	UK source, seen positively, minimal questions asked about sustainability

Table 6: How consumers view rapeseed oil

Three people decided to skip question 9. From the remaining 10 respondents, they considered that the public believes that rapeseed oil is healthy and natural and therefore good for the environment. In addition, consumers like the smell and taste and consider it to be a cooking oil due to its high smoke point.

Q10 Are there specific products where you could see rapeseed oil being used more or being used as an alternative to other oils? if yes please state what kind of products

Respondent	Alternate Uses for Rapeseed Oil
1	Again, no association with GM so Mayonnaise and dressings manufacturers have fewer issues
2	More acceptable in the market place, just not functional in all our products due to pH
3	Yes, (1) as a replacement for palm oil in biscuits, (2) as a replacement for sunflower oil to give a better balance of omega 3 and 6 fats
4	No
5	The functionality of hardened blends of fats delivers higher functionality over rapeseed. Textures and structures are important in many technical products, but in cakes and muffins, this is a highly used material to deliver emulsions/ batter consistencies required for texture, shelf life/ moisture control. Stability is also beneficial over hardened fats.
6	Alternative to palm oil
7	Yes, industrial frying
8	Uk products
9	All ready meals
10	No
11	Mayonnaise and dressings
12	No
13	If there was an easy way to set/harden the rapeseed during production would be used to replace palm in all aspects of the business

Table 7: Alternate uses for rapeseed oil

When asked about alternate uses for rapeseed oil a better balance of omega 3 and 6 fats, alternate to using palm oil, especially in biscuits and cake manufacturing due to its physical properties that make it suitable for batters and emulsions. In addition, it can be used in salad dressings, mayonnaise production and as a replacement for palm oil.

Q11 If you are willing to be contacted for a short follow up an interview, please leave your contact details

Four respondents left their contact details for future correspondence we must be via Campden BRI if required.

Conclusion

The survey was published in two of the monthly newsfeeds distributed from Campden BRI (December 2018 and January 2019). In addition, it was posted on the Campden BRI LinkedIn page and shared periodically. This enabled the survey to be accessed by a wide spectrum of the food and drinks sector. Ultimately, these methods ensured that the survey would be distributed to numerous people within the desired demographical sector.

There were 13 respondents in total, all of which completed the survey and gave feedback relating to their businesses and the use of rapeseed oil within the food and drinks industry.

Over 60% of the respondents described themselves as a large business with over 250 employees. One-quarter of these businesses are in the fats and oils sector, the remaining included bakery, retail and ready meal producers.

Rapeseed oil was reported as the most widely used oil within these businesses.
When asked to describe the desirable traits of rapeseed oil being high in unsaturated fats ranked as the most desirable attribute. Most respondents believed that the nutritional content of rapeseed oil has scope for improvement.

Describing consumer perception of rapeseed oil, the respondents believe that it is perceived as a healthy and natural oil.

Finally, in describing alternate uses of rapeseed oil, any product which currently uses palm oil such as bakery goods, mayonnaise and salad dressings was the most popular answer.

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The quality of rapeseed oil

Responses from crushers, manufacturers and processors

Version 2. Updated on 11th March 2019.

Original version submitted 31st January 2019.

1 Methodology

ADAS carried out a stakeholder review to evaluate industry needs with regard to nutritional value, cooking, processing and storage properties of oil from oilseed rape. A range of quality parameters were investigated including the levels of saturated and unsaturated fatty acids to enhance health and cooking quality, and factors that may enhance manufacturing performance, shelf life and storage potential. ADAS worked with the project team to develop two questionnaire templates to target a) oilseed crushers as producers of rapeseed oil, and b) food manufacturers, processers and retailers who are the key users of rapeseed oil. See Appendix for questionnaire templates.

Oilseed crushers were contacted to understand any implications regarding the oil extraction process. This included identifying the key attributes of oilseed rape that result in high oil extraction, questions around changes in customer demand for oils with specific physical or nutritional attributes, and challenges they face with regard to segregation of different types of oilseed rape seed.

A range of food processors and manufacturers who are using rapeseed oil in different ways were contacted to understand their needs using oil in food production. Questions included their perceptions of limitations on use, and changes in customer demand. Retailers reflecting the different segments of the market (premium, mid-range and discount) were contacted to consider consumer demand and storage aspects for oil sold in bottles, and to understand requirements for use in in-store cafes.

For each group of interview candidates a semi structured interview template was developed with questions relevant to them (crushers, processors and manufacturers and retailers). ADAS used the Smart Survey software programme to collect and collate interview data. Interviews were conducted either by telephone or in some cases businesses preferred to complete the questionnaire online. Responses were reviewed for completeness and in some cases follow up questions were asked. The team aimed to interview a selection of retailers, processors and manufacturers to capture the different uses of rapeseed oil e.g. as frying oil, eating cold, in baked goods, in processed foods, in fast foods.

ADAS identified and contacted a selection of businesses including the two UK based crushers, seven processors and manufacturers using oils in different ways, nine fast food restaurants, three contract catering businesses and five retailers. The response rate is summarised in Table 1 below. The response rate was below what would normally be expected for this type of survey and may have been attributed to many factors such as commercial sensitivity, lack of time or not being able to reach the most appropriate person knowledgeable on this topic.

Table 1 - Stakeholders contacted and number of responses

Type of Business	Businesses contacted	Number of responses
Crushers	2	2 from same company, different teams
Processors and manufacturers	7	3
Fast Food Restaurants	9	1
Contract Catering	3	2
Retailers	5	0

2 Crushers

The two UK based oilseed crushers were invited to participate in an interview and one agreed to participate. The project team were able to interview two different representatives from this company who were in both management and technical roles. The evidence presented here is based on interviews with these two representatives of the same company.

2.1 Types of oil produced

The crusher explained that modern oilseed crushing is done using the solvent extraction process with hexane being the solvent used in this process. Two types of refined and deodorised oils are produced: standard rapeseed oil and high oleic rapeseed oil. High oleic rapeseed oil (HOR) is more stable than standard oil in frying. HOR typically has lower polyunsaturated fatty acids than standard rapeseed oil, hence has less of the most unstable fatty acids than standard oil. Also it can have nutritional benefits as it is high in unsaturated fat and low in saturated fat. Because HOR has lower polyunsaturated fatty acids than standard rapeseed oil, as a stand alone oil, it is not necessarily higher in nutritional benefit than standard rapeseed oil. Once it is heated, HOR is considered more beneficial, because it breaks down more slowly. HOR normally has a price premium compared with standard rapeseed oil.

The two attributes of the seed that have the most influence over oil extraction rates are oil content and moisture content.

2.2 Demand for oils

Customer demand for oil depends on how the oil is to be used. For oil that is sold in bottles for household use, consumers look for low saturated fat and high mono and polyunsaturated fats. This type of oil is perceived as having good nutritional content. Oils with long shelf life are favoured by retailers as well as consumers.

For sales of oil to be used for deep frying as for use in fast food restaurants, catering facilities and in some food processing, customers look for lower polyunsaturated oils as they have a longer frying life. For this user the most important characteristic is for the oil to remain stable when used repeatedly in frying.

2.2.1 Nutritional attributes

The demand for specific nutritional characteristics of rapeseed oil depends upon how the oil is to be used. From the crusher's perspective, oil use may be split into two main categories of use:

1) Salad use, shallow or pan frying
2) Deep frying

For consumers using the oil for salad use, shallow or pan frying, the nutritional attributes they favour are **high levels of: α-linolenic acid (omega-3), linoleic acid (omega-6), polyunsaturated fat, and tocopherol (vitamin E).**

For consumers using the oil for deep frying, **α- linolenic acid (omega-3), linoleic acid (omega-6), and polyunsaturated fat are not desired properties** as increased amounts have a negative impact on the physical properties of oil. The main concern of these users are the physical properties e.g. the stability of oil when used for repeated frying. The presence of high levels of polyunsaturated fats causes oil to break down more quickly in deep frying.

While not identified as a main use of rapeseed oil, it was noted that there **may be some interest by manufacturers of spreads for increased phytosterol content**. While this view was presented by the crusher, we were not able to verify this as the spreads manufacturers contacted declined to be interviewed.

2.2.2 Physical attributes

The physical attributes noted by the crusher as most important are smoke point, oxidative stability, reusability and taste. Smoke point is particularly important when oil is used repeatedly, as the more oil is heated the more it breaks down, which can result in reduced smoke point meaning oil has to be discarded more quickly which has a cost implication. For customers who are using oil for deep frying, they want a high smoke point that does not decline too quickly.

High oxidative stability is also important when oil is used repeatedly. Oils that are high in saturated fats are more stable, so for rapeseed oil which is very low in saturated fat, improving oxidative stability would be desired. **Increased stability of oil can be achieved by lowering the α -linolenic acid (omega-3), and linoleic acid (omega-6) while increasing the oleic acid content, or by increasing the natural antioxidants found in the oil (tocopherols).**

Consumers of rapeseed oil expect a bland neutral taste which is generally achieved when crushing rapeseed in the UK, though the crusher believed that taste was subjective and noted that rapeseed oil is not consumed much in Spain. They felt that this was due to a difference in how they perceive the taste of rapeseed oil as compared to other available oils.

There were no significant concerns noted around shelf life as bottled rapeseed oil generally lasts up to 12 months in the bottle if properly stored. Hydrolysis was not considered a problem as rapeseed oil does not normally contain moisture as long as the seed is of the correct moisture content when crushed.

With regard to colour, customers expect rapeseed oil to be pale yellow to golden in colour. Sometimes it has a greenish tint which is not favoured by consumers. For bottled oil consumers expect the oil to be pale in colour. Crushers achieve this when processing by adding bleaching earth to remove the natural chlorophylls found in the oil. According to the crusher, it would be **advantageous to have paler coloured crude oil direct from the seed as this would reduce cost of production of the oil.**

2.3 Segregation Issues

In general the supply of oilseed rape the crusher receives from the farmers is homogeneous with farmers doing a good job keeping standard rapeseed separate from high oleic rapeseed by load. On limited occasion there may be incidents of field contamination from volunteer rape from previous crops, but this has not posed significant problems.

The crusher's facility is set up to manage the segregation of these two types of seed and oil and generally do this by campaign where they will process standard rapeseed on certain days, then clean equipment and process high oleic on other days. No concerns were raised about grain traders ability to keep these two types of rapeseed separate throughout the supply chain.

Keeping the oils segregated is a big challenge for the crusher. The tanks used to store the oils are prohibitively expensive so they would need to see significant demand for other types of rapeseed oil with new traits to warrant investment in new tanks and methods to handle more different types of oil that would need to be segregated.

Other logistical challenges noted were concerns over traffic, shortages of available lorries for transport, and keeping seed separated based on qualities such as moisture and oil content. The

increased trend toward local provenance with customers wanting to be able to trace the oil back to the oilseed has increased pressure on crushers to put protocols in place to satisfy this demand.

The main area where the crusher feels research funding should be allocated is for breeding resistance to pest and disease to support farmers' ability to produce rapeseed. Changes to pesticide authorisation e.g. withdrawal of neonicotinoids for use on rapeseed crop has made it more difficult to grow rapeseed in the UK. If rapeseed could be modified to be resistant to cabbage stem flea beetle then farmers could grow the crop more reliably, and would be able to produce reliable volumes of good quality crops at economic prices.

3 Manufacturers and processors

Six survey responses were collected from manufacturers, contract catering and fast food businesses. Although contacted, no retailers were able to participate in the project.

3.1 Uses of oil

Respondents commented on the different features they are looking for when selecting an oil, including taste, consistency, nutritional content, and cost. The importance of these features is noted below:

- Taste – the importance of taste or flavour varies depending on the percentage of oil used in the products. If there is a low percentage of oil used in the product, then taste is not that important. Another respondent commented that they are looking for a bland or neutral flavour. Another mentioned the importance of having no rancid or off odours or flavours.
- Consistency – one respondent commented that the importance of consistency depends on the product, with another saying that viscosity is important and another commenting that oil should be clear and uniform
- Nutritional content – one respondent explained that they are looking for typical nutritional values. Another respondent commented that whilst nutritional content is important, in their particular circumstance, the importance is low as they only use a small percentage of oil in their product. One respondent noted that they are trying not to use groundnut oil due to it being an allergen.
- Cost – cost was the most important factor for one of the respondents. They commented that the cost of rapeseed oil is higher than sunflower oil and that they may switch their choice of oil where cost is an advantage. The proximity to factories in the UK was also noted as a factor as transport costs are high.
- Sustainability – two respondents noted that sustainability was an important feature affecting their choice of oil, with one respondent noting that they did not use palm oil. The second respondent said they were trying to use less palm oil, and so are replacing palm with rapeseed and sunflower oil for sustainability reasons and consumer perception.
- Smoke point - **One respondent listed smoke point as a key feature when selecting an oil**. This respondent rated this attribute as very important. One respondent noted that they look for 260C minimum smoke point.

When asked what oils are used within the business, respondents commented that oil choice is related to the suitability of the oil to create the specific product, as well as the choice of oil being influenced by consumer perception, customer specifications, and sustainability considerations. Oil choices also vary by country with preferences in some countries such as Spain not favouring rapeseed oil.

For example, one respondent typically used vegetable oils, including rapeseed, for cakes and biscuits, however, they used palm oil for puff pastry as this contains a higher level of saturated fat which is needed to give structure and form in the finished product. This respondent also used palm oil for doughnuts as this lowers the cost and reduces the oil surface feel to the doughnut.

One respondent noted that rapeseed oil is especially favoured for use as a topical oil spray in manufactured snack foods.

Another respondent commented that rapeseed oil is chosen due to its 'nutty' taste.

Another respondent commented that they use a blend based on their customer's specification, and use animal fats for basting to create particular flavours.

Error! Reference source not found. Table 2 shows the different oils used by the companies surveyed.

Table 2: The use of different types of oils within respondents' businesses

Type of oil	Use within businesses	
Rapeseed	Cakes and biscuits Frying Par Frying Snack foods	Along with sunflower oil, rapeseed is the most widely used oil for marinades and food ingredients Used for Par frying as part of a blend Used in batch baking and as a topical spray for snack food manufacturing
Palm	Puff pastry Frying for doughnuts Snack foods	Used in marinades and food ingredients Used in frying
Olive	Marinades and dressings	Used in marinades and food ingredients
Sunflower	Cakes and biscuits Marinades Par Frying Snack foods	Used for Par frying, Along with rapeseed oil, sunflower is widely used for marinades and food ingredients Batch baking and as topical spray for snack food manufacturing
Vegetable	Cakes and biscuits Frying	Used in baking and frying
Groundnut	Dressings and flavours	Only used by one respondent and is phasing out due to groundnut being an allergen
Other	Dressings	Coconut oil is also used Rapeseed oil mixed with other oils to make flavoured oils for dressings Cottonseed, corn, rice bran, soy

	Snack foods	

3.1.1 Costs and availability

It was raised that vegetable oils are often a blend of sunflower, vegetable and rapeseed oils, with the ratio of each oil tending to vary depending on the season or harvest quality. The cost goes up and down with markets, with prices often aligned with the price of sunflower oil. It was also noted that relative costs are influenced by global supply and demand balances as the oil complex is a traded commodity. As such, the cost position can vary from year to year. It was highlighted that rapeseed can be costly compared to other vegetable types. However, one respondent thought the cost of rapeseed oil was less that other low saturated, high stability oils.

The availability of rapeseed oil was considered good by all respondents. However, it was mentioned that the availability of high oleic rapeseed oil can be tight at times. One respondent had heard about some problems with transport in Europe in 2018 because of the water levels in the river Rhine, however, this didn't affect their organisation.

3.2 Benefits of rapeseed oil

3.2.1 Baking

One respondent used rapeseed oil for baking, using a gas fired oven with convection. The respondent found that rapeseed oil was useful for cake softness and enhancing shelf life of sweet muffins in particular. When baking cakes and sweet muffins, this respondent said that they would choose to use rapeseed oil over other oil types due to this enhancement of shelf life.

Respondents were asked to rate the physical properties that made rapeseed oil a good oil to use (with 1 being poor, and 5 being excellent). The properties which make rapeseed oil a good oil for baking are shown in **Error! Reference source not found.**. The highest rated properties were colour, hydrolysis, taste and shelf life.

Table 3: The physical properties of rapeseed oil which make rapeseed oil a good oil for use in baking

Physical property	Score out of 5 (1 being poor, and 5 being excellent)
Smoke point	2.75
Shelf life	3.25
Oxidative stability	2.33
Hydrolysis	3.50
Polymerization	2.50
Taste	3.50
Reusability	2.75
Colour	4.25

3.2.2 Frying

It was noted that rapeseed oil would have advantages for frying in that it has 'quicker hygiene times' for fryer and freezer cleaning. However, for the company who raised this point, the brand preference was to use sunflower oil or a sunflower and rape blend.

Respondents were asked to rate the physical properties that made rapeseed oil a good oil to use (with 1 being poor, and 5 being excellent). The properties which make rapeseed oil a good oil for frying are shown in 4. The highest rated properties were colour, smoke point, reusability and hydrolysis.

Table 4: The physical properties of rapeseed oil which make rapeseed oil a good oil for use in frying

Physical property	Score out of 5 (1 being poor, and 5 being excellent)
Smoke point	3.00
Shelf life	2.75
Oxidative stability	2.00
Hydrolysis	3.00
Polymerization	2.00
Taste	2.75
Reusability	3.00
Colour	4.50

Table 5 The physical properties of rapeseed oil which make rapeseed oil a good oil for use as a topical oil (spraying)

One respondent noted the benefits of using rapeseed oil as a topical oil which is sprayed on in the snack food manufacturing process. The scores of this one respondent, which are particularly high, are reflected here.

Physical property	Score out of 5 (1 being poor, and 5 being excellent)
Smoke point	5
Shelf life	4
Oxidative stability	3
Hydrolysis	4
Polymerization	4
Taste	4
Reusability	N/A
Colour	5

3.3 Limitations of rapeseed oil

With regards to baking, rapeseed oil cannot be used for making puff pastry. This is because **rapeseed does not have the right texture to create the lamination structure within puff pastry; a slightly harder solid fraction is required. Using a texturized fat benefits puff pastry manufacture and gives less oiliness to the surface feel.**

Rapeseed oil cannot be used in instances where the oil needs to be in solid form, for example as an ingredient for chocolate. The melting point is an important consideration for this process.

One respondent involved in frying processes commented that rapeseed oil is useable, however, it is not the company's oil of choice.

Another respondent producing snack foods noted that **rapeseed oil has a relatively short shelf life (3-9 months) and oxidizes quickly potentially leading to an off-flavour in fried foods. Another limitation noted by this respondent is the GMO status of rapeseed** as non-GMO raw materials are the preference in many countries. This comment was referring to non-UK rapeseed oil as all UK rapeseed oil is non-GMO.

3.4 Nutritional qualities of rapeseed oil

Respondents commented that nutrition is important, and that oil generally needs to be low in saturated fats and higher in good fats. However, this can sometimes not be practical for

the products being made, for example an oil with higher saturated fat is needed for the manufacture of puff pastry. It was also noted that the nutritional qualities of the oil are less important where only a very small quantity is used in the product.

Three respondents were able to comment on the nutritional traits which could make rapeseed oil more suitable for their use. The first suggested an increase in saturated fat and omega-3 were most important, followed by an increase in omega-6, omega-9, Vitamin E and Vitamin K. **The increase in saturated fat would enable them to use rapeseed oil in the manufacture of puff pastry, with the increase in vitamins and omega 3, 6 and 9 giving added value which consumers are looking for.**

The second respondent said they like to use rapeseed oil when they are looking for a healthy oil, but that this varied by country as they are a global food business. The traits they considered to be **most important and would be beneficial if increased are omega-3, omega-6, omega-9, and tocopherol. Traits they would like to see decreasing are saturated fat, vitamin K, phytosterols and polyphenol.** They did not elaborate on why this would be.

The third respondent who is producing snack foods noted that they would like to see an increase in omega-9 and monounsaturated fat, and a decrease in omego-3 and polyunsaturated fat.

4 Conclusions

Feedback from elements of industry dealing with oilseed rape post farm-gate (oilseed crushers, food manufacturers & processors and caterers) identified several rapeseed oil quality characteristics that, with improvement, would increase the use and demand for rapeseed oil including;

- Greater α-linolenic acid (omega-3), linoleic acid (omega-6), polyunsaturated fat, tocopherol (vitamin E) and vitamin K. This will provide enhanced nutritional characteristics for salad dressings and shallow pan frying.
- Lower α- linolenic acid (omega-3), linoleic acid (omega-6), and polyunsaturated fat for deep pan frying. To a large extent these attributes are being provided by HOLL (High Oleic Low Linoleic) varieties, but can they be enhanced further?
- Greater phytosterol content for the manufacture of spreads
- Lighter oil colour. This would reduce the cost of production since bleaching agents currently used.
- Lower smoke point and better oxidative stability to enhance deep frying and baking properties.
- Increase in saturated fat would enable rapeseed oil to be used in the manufacture of puff pastry. Currently palm oil is a key ingredient for this.

New classes of oilseed rape would probably need to be suitable for a large market to justify additional costs of segregating the seed and the oil by large scale crushers. Segregation is less of an issue for small scale crushers (e.g. cold presses).

5 Appendix

5.1 Questions for food processors, manufacturers and catering businesses

Rapeseed oil: Food processors, manufacturers and catering businesses

We are working on a DEFRA funded project with the University of York looking at the feasibility of improving the nutritional, cooking quality, and storage traits of rapeseed oil. The project will explore the genetic variability available through the Oilseed Rape Genetic Improvement Network (OREGIN), and will look at the feasibility of improving oil quality traits. The study is looking at the needs within the sector, the potential for variation, and the feasibility of the different options identified. This will feed into a business plan for a four year programme of work to undertake targeted improvement of oilseed rape against the priority traits. To better understand the needs of the rapeseed oil sector in terms of nutrition, cooking quality and storage, we will be interviewing a range of stakeholders, including food manufacturers, food processors, catering businesses, retailers and oilseed crushers. All data collected will be used anonymously and will feed into the later stages of the project.

Section 1 – Introduction

Q1: Company Name:

Q2: Type of Business:

Q3: Respondent Name:

Section 2 – Uses of oil

Q4: Please give details of the cooking/baking/frying methods you use in your operation:

- Cooking:
- Baking:
- Frying:
- Other:

Q5: What are the key features you look for when selecting an oil for a product? (Please give details for each aspect):

- Taste:
- Consistency:
- Nutritional content:
- Smoke Point:
- Cost:
- Other:
- Comments:

Q6: How does your choice of oil type vary between products? Please explain the decision process used for deciding which oil to use for which product:

Q7: Please give details of any oils used by your company and for which product they are used

- Rapeseed:
- Palm:
- Olive:
- Sunflower:
- Vegetable:
- Groundnut:
- Other oil type:
- Comments:

Q8: How does the cost of rapeseed oil compare to other possible alternative oil types?

Q9: How would you describe the availability of rapeseed oil for your business? Is it readily available in the volume and format that you require?

Section 3 - Benefits of rapeseed oil

Q10: In your experience, what uses are most appropriate for rapeseed oil?

Q11: What physical properties make rapeseed oil a good oil to use? Please rate the following attributes on a scale of 1-5 with 1 being poor and 5 excellent.

	Cooking	Baking	Frying	Other
Smoke point				
Shelf life				
Oxidative stability				
Hydrolysis				
Polymerization				
Taste				
Reusability				
Colour				
Other				

Comments:

Q12: In what situation(s) would you choose to use rapeseed oil over other oil types?

Section 4 – Limitations of rapeseed oil

Q13: What limitations are there in the use of rapeseed oil in your business? Where can it not be used and why?

Q14: What properties make rapeseed oil unsuitable for your use? Please can you comment where these factors inhibit your use of rapeseed oil:

- Smoke point:
- Shelf life:
- Oxidative stability:
- Hydrolysis:
- Polymerization:
- Taste:
- Reusability:
- Colour:
- Other:
- Comments:

Section 5 – Nutritional aspects of rapeseed oil

Q15: How important are nutritional qualities of rapeseed oil to your business?

Q16: Do you think increasing or decreasing the following traits would make oilseed rape oil more desirable for wider use in your business? Please move the slider in your preferred direction of change (where 3 is neutral and 5 is increasing) – for the purposes of email/paper version – put a cross in the selected box

	1	2	3 (neutral)	4	5
α-linolenic acid (omega-3)					
Linoleic acid (omega-6)					
Oleic acid (omega-9)					
Saturated fat					
Monounsaturated fat					
Polyunsaturated fat					

Tocopherol (vitamin E)					
Vitamin K content					
Phytosterols content					
Polyphenol content					
Other (please specify below)					

Comments:

Section 6 – Retail only

Q17: Do you use rapeseed oil in your cafes/ in store bakeries? (If yes, go back to start of questions, if no carry on to section 7)

Section 7 – Retail only – sales of rapeseed oil in bottles

Q18: How important are nutritional qualities of rapeseed oil to your customers?

Q19: Do you think increasing or decreasing the following traits would make rapeseed oil any more desirable for consumers? Please move the slider in direction that reflects your perception of consumer demand (where 3 is neutral and 5 is increasing) – for the purposes of email/paper version – put a cross in the selected box

	1	2	3 (neutral)	4	5
α-linolenic acid (omega-3)					
Linoleic acid (omega-6)					
Oleic acid (omega-9)					
Saturated fat					
Monounsaturated fat					
Polyunsaturated fat					
Tocopherol (vitamin E)					
Vitamin K content					
Phytosterols content					
Polyphenol content					

Other (please specify below)					

Comments:

Q20: What do you think customers believe is the main oil used in vegetable oil?

Q21: Can you describe customer feedback around the use of rapeseed oil?

- Nutritional properties:
- Physical properties:

5.2 Questions for oilseed crushers

Questions for oilseed crushers (implications regarding the oils extraction process)

We are working on a DEFRA funded project with the University of York looking at the feasibility of improving the nutritional, cooking quality, and storage traits of rapeseed oil. The project will explore the genetic variability available through the Oilseed Rape Genetic Improvement Network (OREGIN), and will look at the feasibility of improving oil quality traits. The study is looking at the needs within the sector, the potential for variation, and the feasibility of the different options identified. This will feed into a business plan for a four year programme of work to undertake targeted improvement of oilseed rape against the priority traits. To better understand the needs of the rapeseed oil sector in terms of nutrition, cooking quality and storage, we will be interviewing a range of stakeholders, including food manufacturers, food processors, catering businesses, retailers and oilseed crushers. All data collected will be used anonymously and will feed into the later stages of the project.

Section 1 – Introduction

Q1: Company name

Q2: Type of business

Q3: Name of respondent

Section 2: Crushing activity

Q4: Please describe the oil extraction method you are using

- Solvent extraction,
- Cold pressed
- Comments

Q5: What are the key attributes of oilseed rape seed that results in high oil extraction?

- Specific weight
- Oil content,
- Colour,

- Ripeness
- Moisture content
- Other (please specify)
- Comments

Q6: Are you seeing any changes in demand for oils with specific attributes (physical or nutritional)?

Q7: Which nutritional attributes are you seeing increased demand for?

- α-linolenic acid (omega-3)
- Linoleic acid (omega-6)
- Oleic acid (omega-9)
- Saturated fat
- Monounsaturated fat
- Polyunsaturated fat
- Tocopherol (vitamin E)
- Vitamin K content
- Phytosterols content
- Polyphenol content
- Other (please specify below)

Q8: What physical attributes are you seeing increased demand for?

- Smoke point
- Shelf life
- Oxidative stability
- hydrolysis
- polymerization
- taste
- reusability
- colour
- Other (please specify below)
- Comments

Q9: Which nutritional characteristics result in decreased demand?

- α-linolenic acid (omega-3)
- Linoleic acid (omega-6)
- Oleic acid (omega-9)
- Saturated fat
- Monounsaturated fat
- Polyunsaturated fat
- Tocopherol (vitamin E)
- Vitamin K content
- Phytosterols content
- Polyphenol content
- Other (please specify below)
- Comments

Q10: Which physical characteristics result in decreased demand?

- Smoke point
- Shelf life
- Oxidative stability
- hydrolysis
- polymerization
- taste
- reusability
- colour
- Other (please specify below)
- Comments

Q11: In your crushing facility do you segregate different sources of seed based on oil properties?

Q12: What challenges does segregation cause in the production of oils?

Q13: Do farmers manage to maintain segregated supplies of oilseed rape seed from field to farm gate?

Q14: Do grain traders manage to maintain segregation through to the point of crushing?

Q15: What challenges are observed up the supply chain in maintaining the segregation of oilseed rape crops with different oil properties?

Q16: What logistical challenges do you face in crushing UK rapeseed?

Q17: Do you think that improving traits in oilseed rape would increase demand for oil by your food business customers?

Evidence review of health benefits of rapeseed oil.

Introduction

Compared to other oils, rapeseed oil is considered to be a 'healthy oil' (Public Health England, 2016; World Health Organisation, 2018) with potential health benefits. This is because rapeseed oil is comparatively low in saturated fatty acids and high in monounsaturated fatty acids and polyunsaturated fatty acids including oleic acid (an omega-9 fatty acid), linoleic acid (an omega-6 fatty acid) and alpha-linolenic acid (an omega-3 fatty acid) (see Table 1). Rapeseed oil also contains plant sterols, carotenoids (pro-vitamin a, cold pressed oil only), vitamin K, and tocopherols (vitamin E) with the main health benefits from reduced cholesterol and increased cardioprotection (Gül and Amar, 2006; Lin et al., 2013). Most references to rapeseed oil are referring to canola (often low erucic acid and glucosinolates) or LEAR (low erucic acid and glucosinolate) types of oilseed rape variety. There are varying levels of evidence that support possible health benefits of rapeseed oil, from animal and in vitro studies through to human studies. These include regulation of circulating lipid profiles, effects on blood lipid profile, biomarkers of hemostatisis and inflammation, energy metabolism, insulin sensitivity and cancer and are summarised by the review article by Lin et al. (2013) and represented in **Fig, 1.**

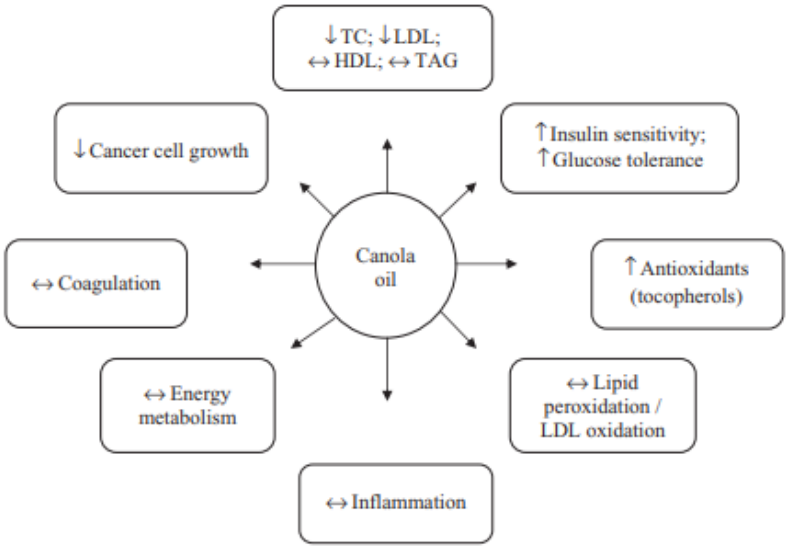

Fig. 1. Evidence of the effect of rapeseed oil on health-related risk factors from Lin et al., 2013. These effects are taken from a range of studies including animal or in vitro through to human studies.

Saturated fatty acids

Fat within foods contains a mixture of different types of fatty acids (saturated, monounsaturated, polyunsaturated). Butter, coconut oil, lard, dripping, ghee and palm oil contain high amounts of saturated fat whereas rapeseed, olive and peanut oils are high in monounsaturated fat. Corn, sesame,

soya, sunflower, linseed (flaxseed) and walnut oils contain high amounts of polyunsaturated fat. High intakes of saturated fat have been shown to raise levels of low-density lipoprotein (LDL, or 'bad') cholesterol in the blood and high LDL cholesterol increases the risk of developing heart disease and stroke(Griffin, 2017). There is also some evidence to suggest a link between saturated fatty acids and cancer, insulin resistance, metabolic syndrome and obesity (Oomah and Mazza, 1999). This is critically important as coronary heart disease is one of the leading causes of human disease and deaths across the world (Finegold et al., 2013)

It is therefore recommended that saturated fat in the diet is reduced and replaced with small amounts of unsaturated fats and oils such as olive and rapeseed oil and spreads made from these (Public Health England, 2016) as this has been found to reduce blood cholesterol levels (Hooper et al., 2015).

Rapeseed oil has relatively low levels of saturated fatty acids (7% or less), the lowest of all main edible oil sources (**Table 1**) (Finglas et al., 2015) making it a healthier option**.** However, in order to use the nutrition claim 'low in saturated fat', products must contain less than 0.75 g/100 ml (for liquids) (European Commission, 2019), which rapeseed oil currently exceeds. Similarly, the UK traffic light front of pack labelling system currently classes food with > 5g of saturated fatty acids per 100 g, or 6 g per portion as high in saturates (Department of Health and Food standards Agency, 2016). Therefore whilst rapeseed oil has the lowest saturated fat level of all the oils, it still carries a red traffic light label for saturates (this means it is high in saturated fats, and should be eaten less often) (Department of Health and Food standards Agency, 2016). Furthermore, the low content of saturated fatty acids also makes oil from some varieties of oilseed rape unstable at high temperatures and therefore less suitable for deep-frying (Möllers, 2002) unless an additional processing step called 'hydrogenation' is performed. The hydrogenation step generates trans fatty acids known to increase plasma concentrations of LDL cholesterol, decrease plasma concentrations of high density lipoprotein (HDL) cholesterol and therefore risk of coronary heart disease (Ascherio and Willett, 1997). High-oleic low-linolenic (HOLL) oilseed rape varieties have been developed through conventional breeding that have less polyunsaturated fatty acids and increased oleic acid. Therefore the oil from HOLL varieties is more stable at high temperatures and suitable for frying (Baux et al., 2013, 2008).

Unsaturated fatty acids

Monounsaturated fat

The nutrition claims 'high in unsaturated fat' and 'high in monounsaturated fat' and the health claim 'replacing saturated fats with unsaturated fats in the diet contributes to the maintenance of normal blood cholesterol levels (MUFA and PUFA are unsaturated fats; oleic acid is an unsaturated fat)' can be used in relation to rapeseed oil (EFSA Panel on Dietetic Products Nutrition and Allergies, 2011; European Commission, 2019).

The predominant fatty acid present within rapeseed oil is the monounsaturated fatty acid most notably oleic acid (61% of total fatty acids) (Table 1) which can lower plasma cholesterol levels in humans (Mensink, 2016; Lopez-Huertas, 2010). The same effect is found when polyunsaturated fatty acids are consumed in place of saturated fatty acids. Experimental and clinical data have suggested that monounsaturated fatty acids have cardioprotective components that regulate plasma lipids and

lipoproteins, inhibit LDL oxidation, and insulin sensitivity (Gillingham et al., 2011; Hunter et al., 2010). Current levels of both monounsaturated and polyunsaturated fats are high in rapeseed oil, with only olive oil having higher levels of monounsaturated fats (Table 1).

Polyunsaturated fat

Rapeseed oil provides both of the essential fatty acids, alpha-linolenic acid (ALA) and linoleic acid (see Table 1) and, due to the quantity of ALA present, the nutrition claim 'high in omega-3' can be used in relation to rapeseed oil, and the health claim 'ALA contributes to the maintenance of normal blood cholesterol levels' may also be used (EFSA Panel on Dietetic Products Nutrition and Allergies, 2011; European Commission, 2019). Rapeseed oil is a good source of long-chain omega-3 polyunsaturated fatty acids (Yang et al., 2013), for example alpha-linoleic acid (Gerster, 1998; Rajaram, 2014). Omega-3 fatty acids have been reported to have numerous health benefits with significant roles in the brain but have also been reported to have positive effects on cardiovascular disease, inflammatory disease, brain function and mental health (including helping with depression and bipolar, behavioural disorders including ADHD, dyslexia, dyspraxia and autism) and also have an immunomodulatory (regulatory adjustment) effect supressing inflammatory bowel disease, rheumatoid arthritis, asthma, cystic fibrosis (for review see Calder, 2017, 2014, 2010). Increasing Omega-3 polyunsaturated fatty acid intake during pregnancy can also benefit the developing foetus (Swanson et al., 2012). There is also limited evidence to show that omega-3 fatty acids are toxic to tumor cells (Laviano et al., 2013). In addition, α-linolenic acid is reported to ameliorate the process of wound healing and promote cell proliferation, and improves liver enzymes, and basal inflammation, but this is based on in vitro work and a single human study (Kruse et al., 2015; Lewinska et al., 2015)**.** In contrast, it is currently not possible to make a nutrition claim for levels of omega-6 (European Commission, 2019). Rapeseed oil has the highest % content of omega-3 as a proportion of the total fatty acid content compared to the other oils listed in Table 1.

Phytosterols

Phytosterols accumulate in rapeseed oil, with higher levels than in palm oil and olive oil (Gül and Amar, 2006; Oomah and Mazza, 1999; Table 1). Phytosterols are cell membrane structural components and have a similar structure and function to cholesterol (Kritchevsky and Chen, 2005), and can lower blood cholesterol through competing for micellar space in the small bowel, thus reducing the absorption of unhealthy cholesterol or stimulating its excretion from the body (De Smet et al., 2012; Kritchevsky and Chen, 2005). This effect has been demonstrated in humans leading to an authorised European health claim (EFSA Panel on Dietetic Products Nutrition and Allergies, 2012). There is some evidence to suggest that phytosterols may protect against various chronic ailments such as cardiovascular diseases (Marangoni and Poli, 2010), diabetes and cancer (20% reduction in cancer risk) (Kritchevsky and Chen, 2005; Shahzad et al., 2017; Tran, 2011). Sterols are 50% higher in rapeseed oil than in soybean oil but two of the major sterols (campesterol and sitosterol) are affected by processing (Gunstone, 2011). Significant portions (up to 40%) of sterols are removed from the oil during deodorisation (Verleyen et al., 2002) and refining (Gunstone, 2004). Furthermore, currently for a health claim relating to phytosterol content, 0.8 g of phytosterol should

be provided per day. Assuming a 20 g portion of rapeseed oil per day with a content of 250 mg per 100 g, this would only provide 50 mg of phytosterol (EFSA Panel on Dietetic Products Nutrition and Allergies, 2010). Thus at present rapeseed oil contains insufficient quantities of sterols for the health claim to be applied. In contrast, other oils (e.g corn oil and soybean oil) have higher values of 845 mg/ 100g and 330 mg/ 100 g respectively. Nonetheless, these values still fall short of the health claim threshold. Rapeseed oil does however outperform olive oil and palm oil in this category. Regardless of oilseed rape variety, the oil was found to reduce total cholesterol by av. 12.2% (ranging between 6.7% to 20.1%) compared to oil typical of a western diet in 5 human studies (Lin et al., 2013).

Tocopherols (vitamin E compounds)

Rapeseed oil contains relatively high levels of tocopherols compared to other oils (**Table 1**) (Gunstone, 2011). Tocopherols are antioxidant compounds (also referred to as vitamin E) which protect cells from oxidative stress (EFSA Panel on Dietetic Products Nutrition and Allergies, 2010). There is also evidence that Tocopherols aid in protection against atherosclerosis, cardiovascular diseases, cataracts, and neural tube defects (Gliszczyńska-świgło et al., 2007; Stocker and Azzi, 2000). The level of tocopherols obtained from rapeseed oil depends on the extraction method (Mirzaee et al., 2014). Oil extraction by cold pressing can result in lower tocopherol levels (Fine et al., 2015). The refining process further decreases the tocopherol content of rapeseed oil, and deodorisation causes the removal of the largest portion of these compounds. Currently, a 20g serving of rapeseed oil can be considered as being 'high in vitamin E', whereas a 10 g serving would qualify as a 'source-of' vitamin E. Whilst high in vitamin E, both sunflower oil and palm oil have higher vitamin E contents than rapeseed oil.

Vitamin K and other components

Rapeseed oil contains vitamin K (Finglas et al. 2015) and has moderate levels compared to other oils (Table 1). Vitamin K contributes to bone development (EFSA Panel on Dietetic Products Nutrition and Allergies, 2009) and promotes the synthesis of an amino acid involved in blood clotting (Foster et al., 2009; Ryan-Harshman and Aldoori, 2004). Currently, a 20g serving of rapeseed oil can be considered as being 'high in vitamin K', whereas a 10 g serving would qualify as a 'source-of' vitamin K (EFSA Panel on Dietetic Products Nutrition and Allergies, 2009). Rapeseed oil is second only to sunflower oil for vitamin K content in Table 1.

Polyphenols and carotenoids are present in higher quantities in cold pressed rapeseed oil than refined rapeseed oil, but currently no health or nutrition claims can be made around them. Studies and quantification of these in relation to human health may lead to a health claim in the future. In contrast, there is an approved health claim for the specific polyphenols present in olive oil, which can be used provided that a particular oil contains the minimum amount per serving, as specified in the conditions of use (EFSA Panel on Dietetic Products Nutrition and Allergies, 2011) .

Conclusions

This review has identified that improvement of some specific characteristics of rapeseed oil could make it more effective than other vegetable oil sources at either enhancing, or causing less detriment, to human health. Priority characteristics for improvement include; unsaturated fatty acids, omega-3 and 6, tocopherols, saturated fatty acids, sterols and vitamin k.

Unsaturated fatty acids. These are beneficial to human health if used to replace saturated fats. Rapeseed oil already has high levels, but some other vegetable sources have greater levels. If levels of unsaturated fats can be increased in rapeseed then it could become the best vegetable source for this characteristic.

Omega fatty acids. Omega-3 and 6 beneficial for human health. Rapeseed oil already has high levels of Omega-3 and is greater than other vegetable sources of oil. Is it possible to further enhance Omega-3 levels? Is it possible to enhance omega-6 to levels that allow a health claim?

Tocopherols (vitamin E compounds). Essential for human health. Rapeseed oil already quite high for these compounds. Can tocopherol content be further improved to give greater content than palm and sunflower oil?

Vitamin K. Beneficial for human health. Rapeseed oil already quite high for these compounds. Can vitamin K content be further improved to give greater content than soyabean oil?

Phytosterols. These may be beneficial to human health with high consumption. Rapeseed oil already has one of the highest levels of phytosterols (behind soyabean and corn oil). Modest increase in content would enable it to overtake soyabean oil for this property, but unlikely to achieve great enough increase to make a health claim.

Saturated fatty acid. This may be detrimental to human health with high consumption. The content is already low in rapeseed oil and breeding of HOLL varieties to improve cooking quality with low saturated fatty acids has already occurred. If the saturated fatty acid content could be reduced to less than 5 g per 100 g, rapeseed oil would no longer have to display a red ‘traffic light’ for saturates under the UK traffic light front of pack labelling system.

Drafted by ADAS with input from the British Nutrition Foundation.

Table 1. Contents of different vegetable oils

	Rapeseed oil	Palm oil	Soybean oil	Olive oil	Sunflower oil	Corn oil	Reference
SFAs (g/100 g food)	6.6	47.80	15.6	14.3	12	14.4	Finglas et al., 2015
MUF (g/100 g food)	59.3	37.10	21.3	73.0	20.5	29.9	Finglas et al., 2015
PUFA (g/100 g food)	29.3	10.4	58.8	8.2	63.3	51.3	Finglas et al., 2015
Linoleic acid (g/100 g food) (omega-6)	20	10.1	52	8	63	50	Finglas et al., 2015
α-linolenic (g/100 g food) (omega-3)	9.6	0.3	7.3	0.7	0.1	0.9	Finglas et al., 2015
Oleic acid (g/ 100 g food) (omega-9)	57.6	37.1	20.8	71.9	20.2	29.4	Finglas et al., 2015
Phytosterols* (mg)	250.7	38.8	330.0	113.8	290.0	845.0	Finglas et al., 2015
Vitamin K (Phylloquinone µg)	112.5	7.90	131.0	57.5	6.3	3.0	Finglas et al., 2015
Vitamin E (mg)	22.21	33.12	16.06	5.10	49.22	17.24	Finglas et al., 2015

Saturated fatty acids (SFAs), monounsaturated fatty acids (MUF), polyunsaturated fatty acids (PUFA).
*Phytosterols include beta-sitosterol, brassicasterol, campesterol, delta-5-avenasterol, delta-7-avenasterol, delta-7-stigmastenol and stigmasterol.

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Our Ref: CEL/JR
17th May 2019

Prof. Bancroft and Dr. Teodor,
Department of Biology (Area 7),
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Wentworth Way
Heslington
York YO10 5DD

Dear Prof. Bancroft and Dr. Teodor,

Prioritisation report for nutritional improvement of rapeseed oil

I read with interest the document "Prioritisation report for nutritional improvement of rapeseed oil" that you shared via the OREGIN website (https://www.herts.ac.uk/oregin/information/rapeseed-oil-traits) and confirm our agreement with your prioritisation of traits for nutritional improvement.

In particular, I consider the improved traits would have a positive impact on food producers by potentially enabling them to make a health claim based on enhanced phytosterol content and by improving both the nutritional value and thermal stability of rapeseed oil by increasing vitamin E content. It would also be of interest to evaluate opportunities for enhancement of vitamin K content.

We would value the opportunity to obtain prototype oil samples for testing and to assess their behaviour in manufacturing, as well as seeing the establishment of a credible supply chain based on new elite varieties incorporating the improved traits.

Yours sincerely,

Jayne Rogers

pp Dr. Craig Leadley
Head of Production & Processing Research Department

Outline research proposal: **Improving the nutritional quality of rapeseed oil**

Ian Bancroft and Roxana Teodor, University of York, 17/5/19

Background

Rapeseed is an essential part of the UK crop rotation. Commercial breeding activities have focussed mainly on improving yield and disease resistance. Beyond compliance with product specifications for human consumption, particularly erucic acid content, there has been little incentive to improve nutritional value.

The "Prioritisation report for nutritional improvement of rapeseed oil" resulted from extensive consultation with stakeholders and highlighted key areas of demand from the food industry. Recent advances in our understanding of oil biosynthesis has led to the development of prototype rapeseed oil with improved thermal stability, a key processing characteristic. Recent advances in our understanding of the biosynthesis of phytosterols and antioxidants accumulated in the oil now make the enhancement of these compounds to the level of making health claims possible.

The supply chain and product validation processes for the improvement of the nutritional and processing qualities of rapeseed oil are daunting. The food industry requires "prototype" oil to assess. This will be expensive to develop, but industry validation will be essential to demonstrate the market pull necessary for commercial breeding of elite varieties. Funding support for at least a 4-year programme will be essential.

Deliverables

1. Development of rapeseed lines producing enhanced content of phytosterols in their oil. This will involve the identification and combining of a set of mutations that control the type and quantity of phytosterols accumulated in the oil and combining with genes conferring oil thermal stability characteristics. U York will conduct the work, with subcontracting to Rothamsted Research.

2. Development of rapeseed lines producing enhanced content of antioxidants in their oil. This will involve the identification and combining of a set of mutations that control the type and quantity of tocopherols accumulated in the oil and combining with genes conferring oil thermal stability characteristics. U York will conduct the work.

3. Evaluation of processes to fortify edible rapeseed oil. This will involve U York working closely with relevant partners, e.g. Cargill, to extract nutritional compounds from industrial rapeseed oil to make them available for nutritional enhancement of edible rapeseed oil.

4. Develop supply chains for the production of prototype oils for food industry evaluation. This will involve UoY subcontracting relevant industry partners, such as ADAS (to grow rapeseed on field scale), BDC (to extract and purify oil) and Nuspec Ltd (a spin-out company of the University of York, active in promoting novel rapeseed oils and developing supply chains).

5. Demonstrate the processing characteristics of prototype oil. This will involve subcontracting to Campden BRI evaluation of nutritional content and processing characteristics of prototype oil in applications such as crisps and French fries, along with undertaking market research activities.

Resource requirements

Accurate costing will depend upon the details of the work required. The ballpark figure for a 4 year project would be **~ £755,000** comprising:

- University of York staff and overhead costs: £400,000
- University of York consumables, horticulture and travel costs: £70,000
- Rothamsted Research subcontracted costs: £100,000
- Campden BRI subcontracted costs: £65,000
- BDC subcontracted costs: £40,000
- ADAS subcontracted costs: £20,000
- Nuspec subcontracted costs: £60,000