III. Discussion

A. General comments

This guidance suggests a range of possible approaches to acrylamide reduction. It is not intended to identify specific recommended approaches. Acrylamide reduction is an area of ongoing research, and some approaches discussed may still be at a research stage, rather than in general use. We recommend that manufacturers evaluate approaches that may be relevant to their particular processes and consider adopting approaches, if feasible, that reduce acrylamide levels in their products. When evaluating approaches, it is important to consider the impact on overall chemical and microbiological safety, nutritional quality, and organoleptic properties (Ref. 31).

Factors affecting acrylamide formation are present at various stages from farm to table, so this guidance is for growers, manufacturers, and food service operators. Sections B, C, and D of the guidance cover raw materials, processing practices, and ingredients affecting potato-based foods, cereal-based foods, and coffee, respectively. Section E provides suggested preparation and cooking instructions on packaged frozen french fries. Finally, Section F informs food service operations of techniques for preparing potato-based and cereal-based foods.

FDA is not suggesting maximum recommended levels for acrylamide in various products at this time. We recommend that manufacturers be aware of acrylamide levels in their products, because knowledge of acrylamide levels is essential for determining the effectiveness of acrylamide reduction techniques. The predominant analytical methods for acrylamide determination are liquid chromatography/tandem mass spectrometry (LC/MS-MS) and gas chromatography/mass spectrometry (GC/MS) (Ref. 42). LC/MS-MS and GC/MS methods, though highly sensitive, are expensive and time-consuming. Also, because acrylamide can vary significantly between identically prepared products, extensive sampling may be required to detect the effects of process changes (Refs. 43-44). One approach to reducing analytical testing (e.g., by LC/MS-MS and GC/MS) is to identify a characteristic that can be monitored as a proxy for acrylamide, such as color or moisture, and calibrate variation in this characteristic to analytically determined acrylamide levels. To be effective, such analysis may have to be performed on a product by product basis. Methods other than LC/MS-MS and GC/MS, such as immunoassays (Refs. 45-49), also have been proposed. FDA has monitored acrylamide levels in foods in the U.S. (Refs. 10-11) and conducted exposure assessments of U.S. consumers (Ref. 50). FDA will continue to monitor acrylamide levels in food to determine, in part, if reductions in acrylamide occur over time.

B. Potato-based foods

i. Raw materials

In potatoes, reducing sugars are present in excess compared with asparagine, and reducing sugar levels are the important factors driving acrylamide formation. Careful control of

variability can significantly impact acrylamide levels in bakery products (Refs. 13, 17, 20, 30). Comparing free asparagine levels in different cereal crops, rye has the highest free asparagine content, followed by wheat, corn and oats, and then rice (Ref. 20). Whole grain products (e.g., whole wheat) have higher asparagine concentrations than refined grains, and produce more acrylamide in finished products (Refs. 20, 30).

Mineral nutrient level is one factor affecting asparagine levels in wheat. Sulfur deficiency can lead to greater asparagine formation, demonstrating the need to maintain sufficient soil sulfur levels (Refs. 16, 19-20, 30). Based on studies in the United Kingdom, a minimum of 15 kg sulfur/hectare[14] was recommended for wheat production, along with sufficient phosphate and potassium (Ref. 16). Sulfur deficiency in only part of a total area under production (e.g., unfertilized field margins) could potentially cause spikes in asparagine levels in certain batches of wheat (Ref. 16). Excessive nitrogen fertilization may increase levels of asparagine in cereal crops (Refs. 13, 20).

Where possible, using wheat varieties low in asparagine, using wheat grown on sites that have shown reduced potential for asparagine accumulation in the past, and using wheat grown with adequate soil sulfate and without excessive nitrogen fertilization (Refs. 13, 20, 30) may help reduce acrylamide formation in cereal products. For the future, development of wheat varieties with low asparagine content under different growth conditions is a promising approach (Ref. 30).

Summary: Using wheat varieties that are lower in asparagine and using wheat grown with adequate soil sulfate and without excessive nitrogen fertilization may help reduce acrylamide in cereal-based foods.

Substitution. Partial substitution of low-asparagine cereals for high-asparagine cereals (e.g., rice for wheat) may allow reductions in acrylamide, while still maintaining desirable product characteristics (Refs. 14, 17, 30, 31). Reducing whole grain content may also reduce acrylamide (Refs. 20, 30-31), but FDA does not recommend this approach given the benefits of whole grains (Refs. 20, 105).

Summary: Partially substituting low-asparagine cereal grains for high-asparagine cereal grains may help reduce acrylamide in cereal-based foods.

Table 5: Summary for CEREAL-BASED FOODS: Raw materials

• **Using wheat varieties that are lower in asparagine and using wheat grown with adequate soil sulfate and without excessive nitrogen fertilization may help reduce acrylamide in cereal-based foods.** • **Partially substituting low-asparagine cereal grains for high-asparagine cereal grains may help reduce acrylamide in cereal-based foods.**

[14] Approximately 13.4 pounds/acre.

important considerations.

Treatment with cations. For breads, fortification of flour[16] with 0.3 to 1 percent calcium carbonate or calcium chloride reduced acrylamide levels compared with unfortified bread (Refs. 30, 110, 113). Magnesium fortification at equivalent levels reduced acrylamide formation in bread to a lesser degree (Refs. 30, 110, 113). Because acrylamide in bread forms primarily in crusts, applying calcium directly to dough surfaces, e.g., in releasing agents or on loaf tops, may be a useful approach (Refs. 30, 110). Sodium chloride may also reduce acrylamide in breads, but Claus et al. (Ref. 114) reported that the optimal concentration of sodium chloride for acrylamide minimization is 1 to 2 percent and is routinely used in industrial bread production. Calcium propionate should be avoided for acrylamide reduction as it caused a greater than 90 percent increase in acrylamide levels in bread (Ref. 30).

For breakfast cereals, many cereals are already fortified with calcium. Manufacturers may want to consider calcium addition for non-fortified cereals (Ref. 30). Sodium chloride also may mitigate acrylamide in breakfast cereals (Ref. 115), but avoidance of excess dietary sodium also should be considered.

For crackers (including crispbreads) and cookies (including gingerbread), calcium and magnesium supplementation showed potential to reduce acrylamide in laboratory trials (Refs. 110, 113), but product quality has been poor (Refs. 30, 110). Also, in laboratory trials, calcium propionate (at 0.35 to 0.75 percent) accentuated acrylamide formation in cracker and cookie doughs (Ref. 110).

Summary: Using calcium supplementation may help reduce acrylamide in non-calcium-fortified breads or breakfast cereals, but the addition of calcium propionate may increase acrylamide levels.

Yeast fermentation. Because yeast use asparagine during growth, some data indicate that yeast fermentation is associated with lower asparagine levels in doughs and lower acrylamide levels in baked cereal goods such as crispbreads (Refs. 17, 30, 111). Longer fermentation time may be a useful strategy to reduce acrylamide formation in breads, crispbreads, and crackers (Refs. 12, 17, 30, 111), although extended fermentation also may have unwanted effects, such as weakened gluten and flatter breads (Ref. 12). As an alternative to longer fermentation, greater quantities of low-gassing yeast can be used to increase asparagine consumption while keeping gas levels constant (Refs. 17, 30, 110). A modified form of yeast that has increased rates of asparagine consumption has undergone the GRAS notification process in the U.S (Ref. 116). It is important to keep in mind that recipe or process changes that affect yeast adversely (e.g., excess sodium chloride) also may affect final acrylamide levels (Refs. 12, 113).

Summary: Using yeast fermentation and changing fermentation conditions may help reduce acrylamide in cereal-based foods.

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[16] In the U.S., "enriched flour" may contain 960 mg calcium/lb flour (21CFR137.165), or approximately 0.2 percent calcium or 0.5 percent calcium carbonate.

Thermal input. Modifications to baking time and temperature can result in lower acrylamide levels in baked goods, breakfast cereals, crispbreads, and other cereal-based foods (Refs. 20, 30, 117). Products can be baked at lower temperatures for longer periods of time (Refs. 12, 17, 30, 117-118). Another approach is to lower baking temperatures during the final stages of cooking when moisture levels are low and acrylamide formation is more likely (Refs. 17, 31, 113). Likewise, it may be possible to increase temperatures earlier in the baking process when higher moisture levels should prevent acrylamide formation (Ref. 31). Potential disadvantages of temperature reductions include slower production lines, lighter color (Refs. 20, 30), shorter shelf life with higher moisture products, and the need for recipe changes (Refs. 17, 30). For breads, convection ovens may give higher acrylamide levels than deck ovens, due to more intense drying of the crust (Ref. 12), while steam baking or baking with lidded pans reduced acrylamide levels compared with other baking techniques (Ref. 30). Alternative baking technologies, such as infrared radiation and air impingement, also can reduce acrylamide levels (Refs. 30, 111), but these technologies may not be in widespread use in the U.S. (Ref. 111).

Summary: Lowering thermal input through modifying baking times and temperatures and considering alternative baking technologies may help reduce acrylamide in cereal-based foods.

Color. For many cereal-based foods (e.g., breads), darker color can be a useful indicator of acrylamide levels, with a darker color being associated with higher acrylamide levels (Refs. 17, 30); however, in a few products, such as some breakfast cereals, darker color may be associated with less acrylamide (Refs. 24-25). Color may be a useful monitor of acrylamide levels during production or when investigating the effects of different baking conditions, but the correlation between color and acrylamide may have to be determined on a product by product basis.

Summary: Monitoring production by using color as an indicator of acrylamide may help reduce acrylamide, but the correlation between color and acrylamide may have to be determined on a product by product basis.

Moisture. For some cereal-based foods (e.g., crispbreads), setting a higher finished moisture level may be a useful strategy for controlling acrylamide (Refs. 30, 37-38). However, too high a moisture level may impact product shelf life or flavor (Refs. 30, 44). Monitoring moisture levels in finished products may also be a good indicator of acrylamide levels in a product with standardized moisture levels (Ref. 30).

Summary: Setting a higher moisture endpoint may help reduce acrylamide in cereal-based foods, and monitoring moisture levels in finished products may be useful as an indirect indicator of acrylamide levels.

Table 6: Summary for CEREAL-BASED FOODS: Processing and ingredients

- **Replacing ammonium bicarbonate in cookies and crackers with alternative leavening agents, while avoiding overall increases in sodium levels, may help reduce acrylamide.**
- **Replacing reducing sugars with nonreducing sugars, using reducing sugars with lower fructose content, and only adding sugar coatings to breakfast cereals after toasting steps may help reduce acrylamide.**
- **Using asparaginase treatment may help reduce acrylamide in cereal-based foods, but dose, contact time, dough water content, pH, and water chlorination are important considerations.**
- **Using calcium supplementation may help reduce acrylamide in non-calcium-fortified breads or breakfast cereals, but the addition of calcium propionate may increase acrylamide levels.**
- **Using yeast fermentation and changing fermentation conditions may help reduce acrylamide in cereal-based foods.**
- **Lowering thermal input through modifying baking times and temperatures and considering alternative baking technologies may help reduce acrylamide in cereal-based foods.**
- **Monitoring production by using color as an indicator of acrylamide may help reduce acrylamide, but the correlation between color and acrylamide may have to be determined on a product by product basis.**
- **Setting a higher moisture endpoint may help reduce acrylamide in cereal-based foods, and monitoring moisture levels in finished products may be useful as an indirect indicator of acrylamide levels.**

<u>Other considerations</u>

The following section summarizes information on proposed acrylamide reduction techniques for cereal-based foods that have produced ambiguous results, and therefore may have not been successfully demonstrated on an industrial scale.

*Treatment with amino acids***.** For breads, addition of various amino acids (e.g., cysteine, glycine) to doughs has been shown in laboratory and pilot plant trials to reduce acrylamide formation in various types of bread (Refs. 12, 30, 98, 114, 119). However, excess cysteine in doughs can negatively affect bread structure and flavor. Glycine also may mitigate acrylamide when added to bread dough or applied as a spray to the surface of the dough prior to baking (Refs. 12, 30, 110, 111, 119). However, glycine in large amounts may reduce fermentation (Ref. 30). Also, a glycine spray needed repeated applications and reduced acrylamide levels only about 15 percent (Ref. 30).

For breakfast cereals, glycine reduced acrylamide formation (e.g., 50-75 percent) in wheat flake cereals in pilot trials, but also caused excessively dark colors and bitter taste (Refs. 17, 30). Producing acceptable flakes required radical changes in the toasting operation (Ref. 17). According to FoodDrinkEurope (Ref. 30), researchers have not been able to mitigate glycine's effects on color and taste, while also meeting requirements for moisture, texture, and shelf life. Added proline and lysine also caused unacceptably bitter flavors (Ref. 30).

For cookies, crackers, and crispbreads, amino acids (e.g., glycine) were successful in reducing acrylamide levels in experimental trials (e.g., approximately 15 percent in savory biscuits to 80 percent in crispbread) (Refs. 30, 113), but poor product color and quality typically resulted (Ref. 30).

Treatment with acidulants. Acidulants such as citric acid reduce acrylamide levels in cereal dough-based products through their interference with the Maillard reaction[17](Refs. 8, 17, 30, 78, 110). A manufacturer of citric acid products stated that it achieved acrylamide reductions of over 60 percent in breakfast cereals in industrial trials, from 30 to 70 percent in cookies and crispbreads in laboratory trials, and up to 90 percent in gingerbread in industrial trials, without effects on taste (Ref. 78). However, other sources report significant impacts in baked goods for acidulants, including sour taste, lessened browning, and a limited practical pH range for doughs (Refs. 17, 30, 113). Another concern is that lowering dough pH may favor the formation of the undesirable chemical byproduct 3-monochloropropanediol (3-MCPD) (Refs. 17, 30, 110, 113). Spraying dough surfaces with acidulants, rather than incorporating acidulants in dough, may avoid some side effects (Refs. 17, 78).

Dough holding time. Higher acrylamide formation was reported in "aged" (up to 3 hours) sweet cookie dough (Ref. 110), leading to recommendations to avoid letting doughs age (Refs. 30, 110). However, a trade organization reported that this approach was not supported by further evidence (Ref. 38).

Rework. Initial research suggested that eliminating use of rework dough[18] could lower acrylamide levels in certain baked goods (Ref. 30). These results have not been born out in manufacturing settings (Refs. 30, 38). More recent information suggests that in doughs with asparaginase, use of rework may reduce acrylamide by providing additional time for the enzyme to react (Ref. 57). Manufacturers may wish to investigate individual products to determine if rework affects acrylamide levels.

D. Other foods

Coffee. Coffee is a significant source of acrylamide exposure for adults. Limited

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[17] The Maillard reaction is a non-enzymatic reaction between sugars and proteins that occurs upon heating and that produces browning of some foods. See http://www.merriam-webster.com/dictionary/maillard%20reaction.

[18] For purposes of this guidance, the term "rework dough" refers to dough that is left over from preparing dough for manufacturing (such as trimmings left from cutting cookies on a baking sheet) and then is fed into the manufacturing process again.

information is available on factors known to affect acrylamide concentrations in coffee.

Robusta beans have somewhat higher acrylamide levels than arabica beans. Dark roast coffee has less acrylamide than light roast coffee (since acrylamide formed early in roasting is destroyed later in the roasting process). Acrylamide levels in roasted coffee decline during long-term storage. Also, different preparation methods (e.g., espresso versus filter brewed) result in different levels of acrylamide in coffee as consumed (Refs. 15, 30-31, 120).

A number of mitigation methods have been suggested for coffee, such as steam roasting, vacuum roasting and asparaginase treatment (Refs. 15, 121-122), but FDA is not aware of any proven mitigation measures. In more recent laboratory and pilot trials, treatment of green coffee beans with asparaginase resulted in lower acrylamide levels (5-45 percent) after roasting compared with untreated roasted beans, but coffee taste was significantly and negatively affected (Ref. 30). A viable commercial process is not yet available (Ref. 30).

E. Preparation and cooking instructions on packaged frozen french fries[19]

For french fries, the recommended maximum cooking temperature for frying is 345-350 ºF/approximately 170-175 ºC (Refs. 30, 43). Providing appropriate cooking instructions on frozen french fry packages may help reduce acrylamide formation safely during final preparation by consumers and food service operators. Examples of such instructions (which may not be applicable to all products) are:

- Cook to a light golden color. Avoid browning fries.
- Avoid overcooking or undercooking.
- Avoid cooking in a toaster oven to prevent overcooking.
- Reduce cooking time when cooking small amounts.

Summary: **Providing appropriate cooking instructions on frozen french fry packages to guide final preparation by consumers and food service operators may help reduce acrylamide.**

F. Information for food service operations[20]

Educating food service workers on the following techniques may help food service operations reduce acrylamide when frying potatoes, such as french fries:

- Following manufacturer directions regarding frying oil temperature. The recommended maximum oil temperature to avoid acrylamide formation is 345-350 ºF (170-175 ºC).
- Cooking fries to a light yellow or golden yellow color.
- If choosing to start with frozen product, cooking fries from the frozen state, not

[19] This section draws on the following sources: Refs. 30-31, 41, 43.
[20] This section draws on the following sources: Refs. 30-31, 41, 43, 123.

pre-thawing for quicker cooking. Cooking frozen fries from the frozen state, as recommended by manufacturers, reduces increased oil absorption at lower cooking temperatures.

- Screening out fines (very small pieces) after frying.
- Avoiding overcrowding fryers, which can cause oil temperature drops followed by temperature surges. High temperatures are more likely to produce acrylamide.
- Removing fried products promptly from the fryer, or using automated fry removal equipment.
- Calibrating fryers regularly to ensure that fryer temperatures are adequately controlled.
- Changing older (overused) oil promptly. Fries prepared in overused oils can appear darker than fries produced in fresh oil, making it difficult to check fry color.
- Selecting fry varieties (e.g., potato variety, fry cut) that form less acrylamide when frying.

Summary: Educating food service workers to follow proper frying techniques for french fries may help reduce acrylamide.

The following techniques may help food service operations reduce acrylamide in foods made from fresh potatoes. Some of these techniques are similar to those covered in Section B:

- Selecting potato varieties for frying or roasting that produce lower levels of acrylamide, e.g., potatoes with lower reducing sugar levels. Potential sources of information on acrylamide formation/reducing sugar levels include distributors, extension agencies, and trade associations. Sweet potatoes can also form acrylamide.
- Following proper procedures for handling fresh potatoes and requesting that suppliers do the same. Proper handling is especially important for potatoes that will be fried or roasted. Examples of such practices (from Section B) include not handling potatoes roughly, storing potatoes in a cool, dark place, and not refrigerating potatoes or storing them in freezing conditions.
- Soaking raw potato slices in water for 15-30 minutes before frying or roasting to lower sugar levels before cooking, but drying pieces before frying.
- Cutting thicker strips or larger pieces of potatoes when frying and roasting and removing very small pieces (fines) from fryers. Smaller potato pieces are more likely to have higher acrylamide levels after frying.
- Frying fresh-cut french fries or roasted potatoes to a light yellow or golden yellow color.

Summary: Selecting potato varieties that are low in reducing sugars for frying or roasting, properly handling and storing potatoes, and using certain cooking practices for foods made from potatoes may help reduce acrylamide in potato-based foods.

The following techniques may help food service operations reduce acrylamide in cereal-based foods:

- Using color as an endpoint when preparing baked goods, such as baking and toasting breads and other baked goods to a light brown, not a dark brown color. In general, lighter-colored bread crusts and lighter-colored cookies will have lower acrylamide levels than darker versions of the same breads or cookies.
- Overly dry or crusty cereal-based foods (such as baked goods) are also likely to have higher levels of acrylamide, so cooking to a moister endpoint may also help control acrylamide levels.

Summary: Baking and toasting breads and other baked goods to a light brown, not a dark brown color; and avoiding overly dry or crusty products may help reduce acrylamide in cereal-based foods.

Table 7: Summary for PACKAGED FROZEN FRENCH FRIES AND FOOD SERVICE OPERATIONS

• **Providing appropriate cooking instructions on frozen french fry packages to guide final preparation by consumers and food service operators may help reduce acrylamide.** • **Educating food service workers to follow proper frying techniques for french fries may help reduce acrylamide.** • **Selecting potato varieties that are low in reducing sugars for frying or roasting, properly handling and storing potatoes, and using certain cooking practices for foods made from potatoes may help reduce acrylamide in potato-based foods.** • **Baking and toasting breads and other baked goods to a light brown, not a dark brown color; and avoiding overly dry or crusty products may help reduce acrylamide in cereal-based foods.**

IV. References

We have placed the following references on display in the Division of Dockets Management, Food and Drug Administration, 5630 Fishers Lane, rm. 1061, Rockville, MD 20852. You may see them at that location between 9 a.m. and 4 p.m., Monday through Friday. As of September 25, 2015, FDA had verified the Web site address for the references it makes available as hyperlinks from the Internet copy of this guidance, but FDA is not responsible for any subsequent changes to Non-FDA Web site references after September 25, 2015.

Any references in this guidance to patents or patent applications are not intended to imply any manner of FDA support, favor, or endorsement.

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