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On Processing Potato. 4. Survey of the Nutritional and Sensory Value of Products and Dishes

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Abstract
Worldwide, hundreds of potato dishes exist, originally composed by cooks in traditional kitchens. Gradually cooks more and more applied processed products as ingredients to save time and to widen their range of dishes. The products are classified according to their features, ranging from thickeners in soups to ready-to-eat snacks. Besides cooks, also the food industry makes ample use of (modified) potato starches, flakes, flour and granulates. Before users prepare meals from purchased ingredients, they only have had visual perceptions of the products as displayed on shelves and in freezers of shops and presentations at the internet. The organoleptic properties, taste, smell and structure of tubers and products are perceived in the kitchen only. Sensory appreciation, likewise, is a function of the types of ingredients in dipping and batter during processing and their role to improve products and flavouring. The nutritional value of tubers, other staples and potato products and dishes is analysed and their enhancement and losses in the production of the raw material and processing are discussed. This paper reviews existing dishes worldwide and how the processing industry derived thereof products for kitchens and the food industry. The nutritive value of tubers and their products is explored. In general, the density of nutritive components of the products is correlated with their water content that decreases from blanched or baked, to fried French fries, chips and the flour. Starch, minerals, some vitamins and antioxidants become less diluted and appear in higher concentrations in products than in the raw material they are derived from. The energy content increases more than proportional in fried products because of adhering oil that per unit weight almost has more than double the energy content of starch. Additives such as sodium acid pyrophosphate (SAPP), batter and dextrin improve the flesh colour of French fries, their crispiness, and staying hot time, and give the golden hue. Flavouring creates a wide range of tastes of French fries and chips. Blanched and chilled products either mixed with vegetables or not are often supplied with sachets of seasoning to be spread on the product while preparing a dish in the kitchen as the seasoning effect would partly disappear when mixed with the chilled product. Different consumer desires from, among others, health and environment perspectives are articulated and it is assessed how easy or difficult it is for

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processors to manufacture suitable products. The paper concludes with future perspectives of consumers among other aspects regarding health and convenience and how the industry reacts with innovations.

Keywords Additives · Cook · Flavour · Health components · Nutritive value · Perspectives · Taste

Introduction: Inception and Research Questions

The objectives of this paper are to review existing potato dishes in national cuisines and how the processing industry derived thereof products that represent these dishes and/or their ingredients and distributes these through retail, the food industry and consumer outlets. Exploring the nutritive value of tubers and products is aimed at determining the influence of processing on the contents of carbohydrates, protein, fibre, minerals and vitamins and some of the factors that are related to human health. More specifically the following questions are addressed.

Potato dishes vary from country to country and among regions, families and generations. In general, worldwide, what is the variety of potato dishes and can they be classified and characterised according to groups with similar attributes? Which manufactured products are ingredients of such dishes prepared in kitchens and which manufactured products are used by the food industry?

In shops, customers can just see the packages of products and only when wrapped in transparent polythene chilled or frozen tuber parts are visible. Package materials differ, such as cartons, polythene bags or aluminum trays, and within the package, units differ in shape and size, individual chips for instance. Some products appear in a wider variety of sizes and shapes than others; which ones? How do they taste and smell and what structure of tubers, and of their products, is perceived upon consumption; how is it described? It all depends on which additives and flavourings were applied and which processing steps they went through. Is it feasible to classify products and attribute sensory perception, visually and olfactorily?

What is the nutritive value of tubers and of their products and how is it altered by processing? How do potato and its products compare to other major staples? Which health claims are there for tubers and their products and which are adverse constituents and how are their concentrations modified through processing? Classifying products according to concentrations of constituents as attributes, will it clarify questions about their health-supporting properties?

The methodology of data processing through the Four-Tier Analysis by formulating and delimiting the domains of, respectively, dishes, senses and nutrients and subsequent condensing data in clear tables, heatmaps and dendrograms is described in detail in Surveys 1 and 2 (Haverkort et al. 2022a, b).

Different groups of consumers need and acquire products from their personal perspectives. That may be for reasons of health (supplements), or concerns (community, environment) or other ones. It has not been mapped which perspectives exist for potato products and how the industry, with what kind of deliberations, is going to deliver the aspired products.

Dishes Domain

Formulation of the Dishes Domain

A potato dish is a meal component in which potato dominates, including side dishes such as French fries accompanying a meal. Before products came to the market, dishes were prepared from fresh tubers that were washed and subjected to operations as discussed in Survey 2 (Haverkort et al. 2022b). The variety of dishes is boundless and is composed in different manners in diverse communities that may be countries, regions or neighbouring groups. Families and generations have their own (succession of) dishes. They all have heating in common as potato starch needs to gelatinise to become digestible; this is contrary to cereals that can be consumed raw, for breakfast for instance. Potato dishes differ mainly by how heating takes place and which non-potato ingredients are added. Potato products are ingredients of dishes (flour and canned as illustration), or just heat and eat (gratin) or just open the package and eat (chips).

Condensation of the Dishes Domain

Wikipedia lists over 150 potato dishes originating from over 40 countries, which shows the widespread presence and use of this tuber. It is considered a vegetable in German and Russian potato salads and samosa, a staple as boiled potato but also fried or mashed or added as cubes in a curry, as a dessert in a sweet doughnut and as a snack such as chips. The description of the dishes reveals how the tuber ends up such as whole, cut into pieces, cubes, slices, chips, wedges and fritters, into smaller particles following grating up to mashing where no original potato structure is recognised anymore. Another feature that distinguishes dishes is the way of heating: potatoes are blanched, boiled, microwaved, poached, deep-fried, pan-fried, salted and cooked or gratinated. Tubers are consumed as peeled or skin-on, boiled whole or in pieces, French fries, chips, hash browns, baked, in the liquids soups and curries, mashed in stews or formed mash or dough in pancakes, gnocchi, balls, bread and croquettes. Where in the past all such dishes were made in kitchens of homes, restaurants and institutions, nowadays, a very large proportion of the dishes and their ingredients are produced in factories and finished after reconstitution where necessary and heated before being served. Table 1 shows a somewhat condensed version of the list with potato boiled, mashed, fried or baked as an ingredient.

Of this alphabetical list with about 175 potato dishes, the Wiki site also gives the origin and a brief description showing how the dish is prepared or what it consists of.

Table 1 List of potato dishes (Wikipedia, 2022) with dishes that are very similar removed (*B.*: batates; *P.* or *p.*: potato, pomme, papa)

a	b	c	d	e
Ajiaco	Chipsi mayai	Home fries	Pickert	Scotch pie
Aligot	Chocolate chips	Hoppel poppel	Pitepalt	Shepherd's pie
All-dressed	Cholera (food)	Hutspot	P. Anna	Shlishkes
Aloo gobi	Chorrillana	Imelletty perunalaatikko	P. dauphine	Siles. dumplings
Aloo gosht	Chuño	Irish stew	P. soufflées	Spanish omelette
Aloo pie	Clapshot	Jansson tempt	Pone (food)	Stamppot
Aloo tikki	Coddle	Jeera aloo	Potato babk	Stargazy pie
Aloo posto	Colcannon	Kartoffelkäse	Potato bread	Steak frites
Aloor Chop	Corned beef pie	Knödel	Potato cake	Stegt flæsk
Bacalhau à Gomes de Sá	Crisp sandwich	Knedle	Potato doughnut	Stoemp
Batates bechamel	Crocchè	Knish	Potato filling	Stovies
B. à Zé Pipo	Croquette	Kouign patatez	Potato kugel	Szałot
B. com natas	Curly fries	Kroppkaka	Potato pancake	Tartiflette
Baeckeoffe	Dabeli	Kugel	Potato salad	Tater tots
Baked potato	Dhoper chop	Kugelis	Potato scone	Tiella
Bangers & mash	Dì sān xiān	Lancashire hotpot	Potato skins	Tombet
Batata harra	Duchess potatoes	Lefse	Potato waffle	Toobs
Batata vada	Dum Aloo	Llapingacho	Potato wedges	Tornado potato
Bauernfrühstück	Far far	Lyonnaise p.	Potatoes O'Brien	Trinxat
Bedf clanger	Farali potatoes	Mashed p.	Potatonik	Triple-cooked chips
Bombay potato	Fish & chips	Meat and p. pie	Poutine râpée forest gateau	Truffade
Bonda	Fish pie	Milcao	Raclette	Tuna pot
Bosnian pot	Fondant potatoes	Munini-imo	Ragda pattice	Vichyssoise
Boxty	Frico	Nikujaga	Rakott krumpli	Woolton pie
Brænd. kærlighed	Fried potatoes	Olivier salad	Rappie pie	Xogoi Momo
Brynd. halušky	Funeral potatoes	Panackelty	Raspeball	Zippuli
Bubble & squeak	Game chips	Panskurar Chop	Reibekuchen	
Caldo verde	Gamja-jeon	P. a la huancaína	Rēwena bread	
Papas arrugadas	Gamja-ongsimi	Papa rellena	Rioja style p.	
Carne asada fries	German fries	Papas chorreadas	Rössypottu	
Causa limeña	Gratin	Pasty	Roasted potato	
Cepelinai	Gratin dauphinois	Patatas a lo pobre	Rösti	
Chairo (stew)	Halal snack pack	Patatas bravas	Rumbledethumps	
Champ (food)	Hash browns	Patatnik	Salade cauchoise	
Chapalele	Hasselback p.	Pâté p. de terre	Salchipapa	
Chip butty	Hodge-Podge	Péla (dish)	Salt potatoes	
	Hoggan	Pichelsteiner	Savoury pattie	

Starting with the first dish and going down, 13 intrinsically different dishes are distinguished, with features that reappear in the other 160 ones in one form or another. These 13 dishes are shown in Table 2. It shows how in cuisines potato is used: as thickener and substance in soups, boiled and eaten warm as such and in stews or cold and sliced in salads. Boiled tubers are either or not mashed, or when formed and fried appear as croquettes or Duchesse potatoes. Baking is done with skin-on whole tubers or as a gratin with slices or scallops in a sauce. Frying is done in a pan with

Table 2 Examples of dishes from Table 1 with typical features that distinguish them as a class

Nr	Dish instance of class	Attribute origin	Few features as attributes	Class of product when manufactured
1	Ajiaco	Colombia	Thickener	Soup
2	Aloo gobi	India	Served as such or cuts in stew, curry	Boiled
3	Aligot	France	Boiled, mashed	Mash
4	Aloo tikkie	India	Fried mash	Formed
5	Baked potato	International	Whole baked, slit	Jacket potato
6	Batates bechamel	Egypt	Sliced or scalloped, baked in sauce	Gratin
7	Batata harra	Lebanon	Blanched, cut sprinkled with oil	Pan-fried, sauteed
8	Bengal potato	India	Deep-fried moist	French fries
9	Bryndzove halušky	Slovakia	Dried mash envelope	Dumpling
10	Chips & dips	International	Deep dry-fried dry	Chips
11	Chuño	South America	Freeze-dried	Dry products
12	Hash browns	International	Formed fried shreds	Hash brown
13	Roast potato	United Kingdom	Oiled, baked chunks	Roast potato

some oil or deep frying as tuber pieces submerged in hot oil but still containing moisture as opposed to chips. Dumplings are cooked stuffed potato doughs. If deep-frying is done with very thin slices it results in chips. Chuño is prepared by reconstituting freeze-dried tubers and hash browns are shreds formed as patties, seasoned, with onion added and pan- or deep-fried. Roasted potatoes are cut tuber chunks, blanched and pre-fried or sprinkled with oil and baked in the oven at high temperatures.

Potato Products in Dishes and Their Users

From homemade dishes starting with fresh tubers, the potato processing industry gradually (Survey 1, Haverkort et al. 2022a) produced more and more ingredients and complete dishes. Also, new products previously not prepared in kitchens were developed and commercialised. Table 2 lists in alphabetical order such dishes, the food ingredient from the shop or the market, the process it went through, how it is sold and what kitchens in restaurants, institutions and homes need to do after opening the package. Most favourite replacements of kitchen preparations are French fries and hash browns (still needing deep or pan-frying) and peeled blanched tuber(s) (parts) still needing boiling or (pan) frying in the kitchen. Very frequently purchased but rarely prepared by cooks are chips, croquettes and dumplings. Fibre, protein and expanded or stackable chips are not made in kitchens but are on offer on the market.

The purchased food components, potato products, are listed in Table 3 and cover the whole range of basic products made by the processing industry (starch, fibre and

Table 3 Homemade dishes of Table 1 from (partly) manufactured ingredients/components

Dish (main example)	Purchased food component	Basic processed ingredient	Usual status at purchase	Kitchens preparation
Andean stew	Chuño	Freeze-dried pieces	Dried tuber (pieces)	Reconstitute, cook
Baked potato	Jacket potato	Pre-baked tuber	Frozen, Chilled	Bake, grill, microwave
Cooked	(Baby) tubers, slices	Pre-cooked, chilled	Chilled vacuum packed, canned	Heat/fry
Sauteed	Tuber parts	Pre-cooked, roasted	Chilled vacuum packed	Pan-fry
Croquette	Filled/dough	Flakes	Frozen	Thaw, deep or air fry
French fries	Fries	Par-fried chips	Frozen, chilled	Deep or air frying
Gnocchi	Dumpling	Formed flour dough	Chilled/frozen/dry	Steam, boil
Gratin, scalloped	Whole dish	Gratinated slices	Whole, frozen	Thaw, bake in oven
Hash brown	From shreds	Pre-cooked shreds	Frozen	Deep fry
Ketogenic diet	Potato fibre	Skin mainly	Dry grainy substance	Reconstitute, boil or add wheat flour (bread)
Kugel	Casserole	Flakes, flour	Frozen	Thawing, baking
Pan cake	Formed dough	Flakes or flour	Frozen	Pan-fry
Scalloped	Raw dry slice	Air-dried raw slice,	Loosely packed	Reconstitute, heated
Roasted	Heated cuts	Pre-fried cuts	Frozen, loosely packed	Hot oven 200 °C
Snack	Popped chips	Swollen hot pressed slice	Dry, loosely packed	Ready
Snack	Airy chips	Expanded heated pellet	Dry, loosely packed	Ready
Snack	Coated nuts	Starch coating	Dry, loosely packed	Ready
Snack	Stacked chips	Deep-fried dough slices	Dry, stacked in a box	Ready
Snack	Oven chips	Oven-baked dough slices	Dry, loosely packed	Ready
Snack (tuber)	Chips	Deep-fried tuber slices	Dry, loosely packed	Ready
Soup (dry)	Soup powder	Flakes, modified starch	Powder	Add water, heat
Soup (liquid)	Liquid soup	Flakes, modified starch	Liquid	Heating
Sport drink	Supplement	Protein	Powder	Add liquid

protein) as well as prepared ones (cooked, dried, formed and fried). The processes underlying the products were addressed in Survey 1 (Haverkort et al. 2022a).

Products for the Industry

In Survey 2 (Haverkort et al. 2022b) it is shown how potato starches are modified to be used by the food and nonfood industry. Several potato products from the processing industry, besides being employed by the end-users, cooks in kitchens, also find their way to the food companies such as bakeries for bread and biscuits, general food industry as thickeners and extenders and as ingredients for patties, soups and gratins (Table 4). The majority of such intermediate products are the standard flakes, as such producing a mash for food services. When finely ground they serve as binder and thickener for the general food producers. When mixed with granulate they better mimic freshly cooked and dried tubers so suit making salads and side dishes. When ground very finely it produces a potato flour not fit for making a mash but used as a thickener and extender. Low peel, low leach flakes are made of very lightly peeled and blanched tubers that only rehydrate when part of a dough (Mu et al. 2007), for, e.g., pizzas and for the production of pellets. Standard granules are not soluble in cold water. With their mouth feel of boiled and ground tubers, they are at the base of, among others, hash browns. Cut (as slices, cubes and shreds), blanched and dried but not ground tuber parts, upon rehydration reappear as cooked potato parts and as such find their way to the food industry for processing into soups, hash browns and gratins. Table 4 gives an overview of these products, some typical characteristics, how they are rehydrated and their main use by the potato processing and other food industries.

Quantification of the Dishes Domain

The previous tables successively displayed the variety of traditional potato dishes, classes of products made by the processing industry based on these dishes and how products are used as ingredients to prepare dishes to complete the cycle. The heatmap in Table 5 demonstrates the 13 classes of dishes listed in Table 2, extracted from Table 1. The chosen attributes concern three frequencies, the first one is how often such a dish is made by cooks in kitchens, most frequently boiled and rarely prepared as chips. Basic ingredients bought are flour or chilled blanched tuber parts that cooks deploy to make more intricate dishes, salads and soups for instance. Frequently found in supermarkets are French fries and chips that also have the least local image, least frequent roast potatoes. The other attributes speak for themselves.

The heatmap shows that the highest average score of 4.0 is for French fries that only have a low score for not being a local dish. Potato soup has the lowest average of 3.0 because it is relatively rarely cooked and has a low dry matter concentration, and when there are no potato chunks present and potato is used as a thickener, the original potato structure is gone. In general, the red and the green colours cancel each other out, resulting in average scores between 3.0 and 3.5. The mean value of

Table 4 Use of potato (intermediate) dehydrated products by food industry and services, after PotatoesUSA (https://www.potatogoodness.com/ingredient/resources/dehydrated-potato-varieties/)

Product	Characteristics	Reconstitution	Main use
Modified starches	White starchy powders	Substantially improved over native starch	Food industry (baking, batter, clear thickener)
Standard flakes	Bright white, coarsely ground Finely ground: thickener, breading, binder	Water + milk at 77 °C (not 100 °C to avoid stickiness) (cold water soluble)	Potato taste mash for food service, bakeries, general food manufacturers
Mashed potato mixes	Flakes and granulate mixes, add taste highly convenient	Water + milk at 77 °C (not 100 °C to avoid stickiness)	Mash for salads, main and side dish (found in supermarket, restaurant, institution)
Low peel, low leach flakes LP/LL	Less white, finely ground, starchy structure	Only rehydrated in cohesive dough mixture, convenient handling	Food industry pelleted snacks, cookies' ingredients, adds flavour to pizza dough
Standard granules	Toughened cell walls cause granular structure. Taste and feel as mash of fresh tubers	Added to boiling water and whipped (not cold water soluble)	Institutions as potato mash, also for hash browns, extruded products (pellets), thickening agent
Flour (granular < 420 µm and fine < 177 µm)	Produces sticky substance with water, not for mash	Not rehydrated by itself always is an ingredient for softer mouth feel	Thickener, extends other flours, ingredient in biscuits
Slices, dices, shreds	Dehydrated blanched tuber parts	Hot water added, then used as ingredient	Canned soups, stews, hash brown, casserole, gratin

Table 5 Heatmap of 13 classes of dishes with 10 attributes

		Standard		
High	a b c d e f g h i j	Frequency preparation in kitchens Frequency of using a basic processed products as ingredient Frequency as finished products on sale in supermarket Image as a local, not global, dish Proportion of potato in the dish Preparation time based on fresh tuber Dry matter concentration Cooking temperature Serving temperature Visibility of original potato structure	Low	

Nr	Classes of dishes	a	b	c	d	e	f	g	h	i	j	Average
1	Soup											3.0
2	Stew											3.3
3	Boiled											3.3
4	Salad											3.4
5	Mash											3.3
6	Formed											3.2
7	Hash brown											3.5
8	Baked											3.7
9	Gratin											3.5
10	Pan fried											3.7
11	French fries											4.0
12	Roast											3.7
13	Chips											3.3
Average		2.6	2.8	3.8	2.8	4.4	3.9	3.1	3.9	4.0	3.2	3.5

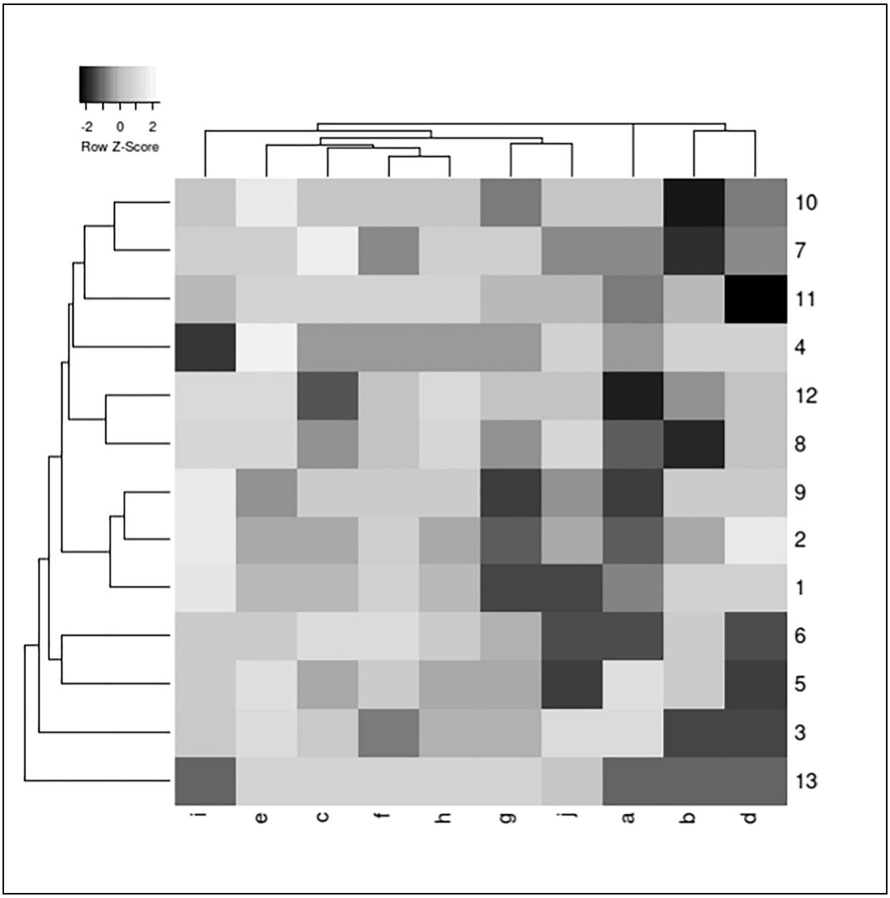
the attributes across all dishes is low, for often they are cooked and are being considered local food. High scores are for the potato content and for serving temperatures of the dishes, all hot except salad and chips.

Clustering of the Dishes Domain

Clustering the products as seen in the dendrogram of Table 6 reveals a few meaningful twins, the closest being stews and gratins, with soups nearby. Pan-fried potato and hash browns (rösti) are quite similar and so are baked and roasted tubers. Mash and formed mash-based products are also twins but at a considerable distance. Chips do not belong to any cluster and stand alone.

The attributes also have twins: preparation time and cooking temperature (the higher the temperature the more time it takes), dry matter and potato structure are twins (the drier the more the products shows tuber features). Albeit at a larger distance, the rightmost twin indicates that deploying basic products still needing several preparation steps by the cook have more local appeal.

Table 6 Dendrogram of the classes of products 1–13 (Table 5) and the attributes a–i (Table 5)



Senses Domain

Formulation of the Senses Domain

Humans have five basic senses that potato and its products all appeal to: sight, touch, smell, taste and hearing. Products are seen in supermarkets and on the plate and appreciated, they are touched by hand when eating chips and have a mouth feel. They have a taste and can be smelled. Depending on the crunchiness of the product, they can be heard as well. All five senses belong to this domain and are addressed in the following sections.

Condensation of the Senses Domain

Taste and Structure of Tubers and Products

When eating potatoes and their products, besides how they look, three sensations matter: their taste, their smell and their texture or mouth feel (Taylor et al. 2007). These are summarised in Table 7. Potato cells contain soluble substances—non-volatile compounds responsible for the five basic tastes: bitter, salty, sour, sweet and umami (Solms 1971). Solms and Wyler (1979) attributed the taste of boiled tubers mainly to umami from an array of glutamate compounds and hardly to acids, sugars and salty molecules. During frying, at the Maillard reaction the release of such substances increases (Beksan et al. 2003). Maga (1994) reported pyrazines and degraded fatty acids to deliver typical potato smell and taste in raw and cooked tubers and that the Maillard reaction produces many volatiles. Mash produced from potato flour has less taste and smell related compounds than cooked tubers but French fries and chips have a stronger smell than boiled tubers. Glycoalkaloids at relatively high concentrations lead to off-flavour (Ross et al. 1978) but at higher concentrations, above 20 mg per 100 g, they become toxic.

The mouth feel of cooked tubers and their products is as important as their smell and taste. Lugt (1961) proposed a description of the potato texture consisting of five properties (Table 7) and four degrees of expression such as for structure, for instance fine, fairly fine, slightly coarse and coarse where Table 7 only shows the two extremes of each characteristic. Disintegration of potato tissue in reconstituted mash is moderate; in chips, it is complete. Obviously, mash is softer and more humid and has a finer structure than boiled tubers and chips are extremely firm, dry and coarse.

Visual Aspects

Besides the taste and mouth feel of tubers and their products, their colour, size and shape are of importance for trade and consumption. Consumer preferences for size (baby tubers < 20 mm diameter, small tubers about 35 mm, middle-sized tubers ≈ 45 mm and large tubers > 55 mm) differ per consumer and depend on the meal ingredient. Pan-frying is done with baby tubers or chunks of larger ones and for jacket potato, baked, large tubers are needed. French fries are made of long large tubers and chips of small round ones. For starch and flour size hardly matters, although losses of peels are reduced when tubers are larger.

French fries come in many sizes and shapes with MacFry, specifications for MacDonalds, thin and long at one end of the spectrum and Flemish cut at the other. Formed products are also made in different sizes and shapes. Peeled or skin-on is another visual aspect but is also coupled with taste and mouth feel. The first column in Table 8 represents the range of shapes of French fries. Chips appear in different sizes and shapes, flat or undulated with varying depths of the furrows. Of the natural chips made of thin slices of tuber, all individuals differ both in shape and size but stackable and expanded chips all have the same size and shape. Chilled tuber parts

Table 7 Description of flavour and texture of cooked potato tubers and a selection of their products

Taste, feel	Elements	Range	Remarks	Salted only, compared to boiled tuber		
				Mash from flour	French fries	Chips
Flavour	Non-volatile compounds	Sweet, sour, salty, bitter and umami	Umami taste (glutamates) dominates. Enhanced in Maillard reaction	Diminished umami	Increased	Still more increased
	Volatile compounds	Pyrazines, degraded lipids	Maillard reaction creates many volatiles	Diminished smell	Increased smell	Somewhat increased smell
	Glycoalkaloids	Toxic over 20 mg/100 g	Off-flavour (bitter) at high concentrations in boiled tubers	Not an issue	Not an issue	Not an issue
Texture	Disintegration	None to completely disintegrated		Moderate	Slight	Complete
	Consistency	Firm to soft		Softer	Firmer	Firmest
	Mealiness	Not mealy to dry (also flouriness, waxiness)		Less mealy	Mealier	Hardest
	Dryness	Humid to dry		Moister	Drier	Driest
	Structure	Fine to coarse		Finer	Coarser	Coarsest
Flavour	Non-volatile compounds	Sweet, sour, salty, bitter and umami	Umami taste (glutamates) dominates. Enhanced in Maillard reaction	Diminished umami	Increased	Still more increased
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	Dryness	Humid to dry		Moister	Drier	Driest
	Structure	Fine to coarse		Finer	Coarser	Coarsest

also come in many shapes to prepare boiled, pan-fried and fried dishes or ingredients. The colour of the product matters too. For example, consumers in the UK and USA prefer white-fleshed products whereas in most other countries creamy coloured tubers have preference. French fries and chips are not dark coloured and dextrose is added to the batter to enhance the 'golden' colour. Some flavourings of chips act as a dye and alter their hue such as the orangish bell pepper (paprika) powder. Besides visual observations in shops, the internet increasingly offers presentations that allow users to form an opinion about the product as a basis for purchase.

Additives and Flavourings

Depending on the specification of the finished product, a range of additives is available for different operations. For fried products consisting of tuber parts (not formed), the parts are dipped in a solution of SAPP (sodium acid pyrophosphate) to avoid after-cooking darkening (Calder et al. 2012), added dextrose in the SAPP solution enhances the golden colour (Van Loon, 2012) and a batter of various starches makes the fries crispier and keeps them warmer for a longer period which is an advantage in quick-service restaurants. An NDTV-Food (2021) website mentions as ingredients in McDonald's French fries: 'Potatoes, vegetable oil (canola oil, soybean oil, hydrogenated soybean oil with tertiary butylhydroquinone (anti-oxidant) and dimethylpolysiloxane (anti-foaming)), natural beef flavour (wheat and milk derivatives), citric acid (preservative), dextrose, sodium acid pyrophosphate, salt'. Formed products are seasoned and hash browns often contain onion.

Table 8 enumerates the additives in dipping (e.g., SAPP) and batter of French fries (second column in Table 8) and of chips (oxygen in the package replaced by nitrogen) and blanched and chilled products usually accompanied by an anti-oxidant. The bulk of frozen French fries, battered or not, is not flavoured. A substantial proportion, however, especially in the UK market, contains batter with a range of tastes as shown in the third column of Table 8. Snacks, chips and expanded snacks have a wide range of flavours besides the original sweet pepper (paprika) and salt and vinegar additions. Market leader Frito-Lay according to their website produces over 150 flavours ranging from simple kiwi to intricate Spanish chicken paella.

Quantification of the Senses Domain

The thirteen basic products addressed in Table 2 are present in Table 9 with senses-related attributes. Potato mash has the lowest average score of all products and only has some potato flavour and mouth feel. Also, soups and simply boiled tubers have low scores with soups having many ingredients with small boiled tubers visible. The highest average is for chips with high scores for all sensory appreciations except for the original tuber texture that has gone completely with deep-frying till all water is gone. Another high score for many of the same attributes but with a lighter weight is for French fries that outperform chips with the assortment of shapes.

The highest score over all products is for flavour intensity (4.0), which is high for all products except for boiled and mashed tubers. Low scores (2.9) are for the variability of

Table 8 Not exhaustive list of shapes, additives and flavourings of French fries, chips and blanched and chilled products

Frozen French fries			Chips		Blanched chilled[d]	
Cuts[a]	Additives	Flavours[b]	Shapes	Flavours[c]	Shapes	Flavours
Strait cut	Oil[1]	Cheese	Flat, original	Lays chips worldwide offers over 150 flavours. Here follows a few: - Salt and pepper - Sour cream and onion - Honey, mustard - Spanish chicken paella - German sausage - Scottish haggis - Fried green tomato - Hot and sour fish soup - Kiwi	(Baby) tuber	Waxy
Curly cut	Anti-oxidants	Bacon	Undulated		Sections	Floury
Crinkle cut	Preservatives	BBQ smoke	Furrowed		Round slice	Bell pepper
MacFry	Dextrose[2]	Chimichurri	Ribbed, ridged		Oval slice	Gratin
Flemish	SAPP	Garlic	Popchips[5]		Crinkled slice	Ham
Wedges	Salt	Beef dripping	Kettle chips[6]		Small discs	Onion
Tater drums	Wheat, rice flour[2]	Beer (IPA)	Stackable[7]		Cubes	Vegetable mixes
Lattice cut	Milk derivates	Paprika	Sticks		Wedges	Burgundian
Twister	Dextrin[2]	Cayenne pepper	Wafer, lattice		Hasselback	Texan BBQ
Skin-on	Bleached starch[2]	Turmeric (curcumin)	Extruded, expanded. Many two and three dimensions		Skin-on	Bistro
Wedges	Gluten free[3]	Lemon oil			French fries in various cuts, see first column	
Chunks	Pea fibre	Citric acid				
	Xanthan gum[4]	Onion, parsley	Additive: nitrogen (CA)		Additive: anti-oxidant	

[a]From Haverkort et al. 2022b

[b]Examples taken from https://www.mccain.co.uk/products/

[c]Examples taken from https://www.listchallenges.com/lays-chips-flavours-worldwide-list

[d]Mainly based on the inventory presented in Haverkort et al. 2022b

[1]Examples: palm, canola, soybean, sunflower, groundnut

[2]Component of batter

[3]Additives devoid of gluten

[4]Stabiliser

[5]Popped, not fried, dough based, regular shape

[6]Thicker than original flat

[7]Saddle shaped, all identical

Table 9 Classes of 13 potato product-based dishes and their 12 sensory-related attributes

High/Much/Many/Dark		Attribute	Low/Little/Few/Light
High	a	Variability in shapes per product unit within package	Low
Much	b	Variety in weight/size among packages of the same products	Little
Many	c	Crunchiness	Few
Dark	d	Additives beside potato	Light
	e	Flavour intensity	
	f	Variety in flavours	
	g	Smell intensity	
	h	Colour intensity	
	i	Skin-on visibility	
	j	Variety in shape of products	
	k	Original tuber shape visible	
	l	Original tuber texture sensible	

Nr	Classes of dishes	a	b	c	d	e	f	g	h	i	j	k	l	Average
1	Soup													2.6
2	Stew													3.2
3	Boiled													2.8
4	Salad													3.1
5	Mash													1.9
6	Formed													3.1
7	Hash brown													3.5
8	Baked													3.5
9	Gratin													3.2
10	Pan fried													3.7
11	French fries													3.9
12	Roast													3.8
13	Chips													4.2
Average		2.9	3.2	3.1	3.4	4.0	3.2	3.7	3.3	2.6	3.1	2.9	3.6	3.3

product units within a package which is only very high for chips with each unit having a different shape, size and colour and also for the original tuber still visible (2.9) with only a very high value for baked skin-on tubers.

Hierarchical clustering indicates chips to stand alone and are not grouped with any other dish. The three moist dishes soup, stew and gratin are in one cluster beside the group mash, formed mash and shreds (hash browns). This clustering is not unlike that of Table 6 with a different set of attributes that were not related to senses. The attributes reveal four twins: more additives are associated with more variety in flavours, smell and flavour coincide, crunchy chips also vary much in shape and skin-on reveals most original tuber features.

Nutrients Domain

Formulation of the Nutrients Domain

Nutrients are substances living organisms need to sustain themselves. The most important ones to deliver energy to animals are carbohydrates mainly and fat and for building material for tissues, protein is especially vital. In the following nine tables nutrients are presented. The first three tables are dedicated to the comparison of nutrient concentrations in potato to some other root and tuber crops and potato flour with wheat flour. The following table shows the range of nutrient concentrations in tubers of different varieties and origins, variety, environment and crop management influence tuber composition strongly, especially for low concentration constituents such as vitamins, antioxidants and minerals. Four tables are dedicated to the nutrient composition of potato dishes with different varieties of dishes and origin of data. The last table in the section ‘Condensation of the Nutrients Domain’ discusses some health claims specifically of potato nutrients.

Condensation of the Nutrition Domain

Comparison with Other Foods

The value of staple crops for feeding humans and animals is mainly expressed by the two main components: the energy content in its carbohydrates (sugars, fibre and starch) and its protein content as an essential element of body tissue but also a deliverer of energy, both 17 kJ/g beside lipids that deliver 37 kJ/g. The European Union (EU, 1990) food industry labels its food according to its contents of fat, ethanol, proteins carbohydrates, organic acids and fibre and derives from it the energy content of the product according to European legislation. There are more nutrients such as minerals in food but these are considered noncaloric so their value is zero. Besides these components, other constituents are important such as minerals among them calcium in bones and teeth and vitamin C (ascorbic acid) essential for an array of bodily functions. The tuber crop potato compares well with other tropical root and tuber crops such as sweet potato, yam, taro, and cassava (Table 10). Potato has the lowest proportion of dry matter, carbohydrates mainly, about half that of cassava. In other words: potato has the highest proportion of water of these crops. The two crops with the highest proportion of carbohydrates, sweet potato and cassava, have the lowest protein concentration. Potato is low in energy but frying makes it a high-energy food. Resistant starch is present and increases upon retrogradation, reducing sugars contributing to acrylamide formation and chlorogenic acid to after cooking

Table 10 Contents of energy, carbohydrates, protein, calcium and vitamin C per 100 g edible part in the five major root and tuber crops (Woolfe 1987)

Crop	kJ/100 g	g carbohydrates	g protein	mg Ca	mg vitamin C
Potato *Solanum tuberosum*	335	18.5	2.1	9	20
Sweet potato *Ipomoea batatas*	485	27.4	1.4	33	26
Yam *Dioscorea* spp.	444	24.2	2.2	25	9
Taro *Colocasia* spp.	423	23.5	1.9	38	6
Cassava *Manihot esculenta*	607	35.2	1.1	38	36

darkening. Part of its protein, patatin, a storage protein, comprises about 40% of all proteins (Alting et al. 2011) and is high in lysine but low in methionine and cysteine so complements cereals. Its antioxidant concentrations vary considerably with flesh colour, carotenoids high in yellow and anthocyanins high in red-fleshed tubers. The calcium concentration varies widely among crops with potato lowest and so do those of vitamin C with taro and yam being relatively low but the other crops are effective sources for the ascorbic acid needs of humans.

The following root and tuber crops globally or regionally play a role as a staple (Chandrasekara and Kumar, 2016): potato (*Solanum tuberosum)*, country potato (*Solenostemon rotundifolius*), cannas (*Canna edulis*), arrow root (*Maranta arundinacea*), taro (*Xanthosoma sagittifolium*), yam (*Dioscorea alata*), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*) and elephant foot (*Amorphophallus paeoniifolius*). Table 11 compares the composition of potato, macaroni and rice with two other major starch root and tuber crops sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*). These have a higher dry matter concentration mainly due to a higher concentration of carbohydrates resulting in substantially higher energy content which is for cassava more than twice that of potato.

Table 11 Nutrients in 100 g of three raw root and tuber crops, pasta and rice. (USDA NAL 2015; Furrer et al. 2018; USDA 2022)

Category	Nutrients	Unit	White potato	Sweet potato	Cassava	Macaroni cooked	Brown rice cooked
Composition	Dry matter	g	21	26	38	38	27
	Energy	kJ	290	361	672	663	466
	Protein	g	1.7	1.6	1.4	5.8	2.6
	Total lipid	g	0.1	0.1	0.3	0.9	0.9
	Carbohydrate	g	15.7	20.1	38.1	31.0	23.0
	Dietary fibre	g	2.4	3.0	1.8	1.8	1.8
	Total sugar	g	1.2	4.2	1.7	0.56	0.35
Minerals	Calcium	mg	9	30	16	7	10
	Magnesium	mg	21	25	21	18	43
	Potassium	mg	407	337	271	44	34
	Phosphorus	mg	62	47	27	58	83
	Iron	mg	0.70	0.61	0.27	0.50	0.42
	Zinc	mg	0.29	0.30	0.34	0.51	0.63
Vitamins	Ascorbic acid	mg	19.70	2.40	20.60	0	0
	Thiamin	mg	0.07	0.08	0.09	0.02	0.10
	Riboflavin	mg	0.03	0.06	0.05	0.02	0.02
	Niacin	mg	1.07	0.56	0.85	0.40	1.50
	Vitamin B6	mg	0.203	0.209	0.088	0.050	0.150
	Folate (DFE)	µg	18	11	27	7	4

The protein concentration is lowest of cassava but this crop has, although still modest, the highest lipid concentration and the crops are not noted for the presence of high-fibre levels. Sweet potato, obviously, has the highest concentration of sugar and apparently also the highest calcium level. The concentrations of the other minerals except for the high potassium levels in potato are more or less similar in all three crops. Both potato and cassava contain substantial amounts of ascorbic acid, sweet potato not so and is also relatively low in folate. The energy concentrated in the foods is closely correlated with the dry matter concentration that is highest for cassava and pasta, hence their high energy content of over 650 kJ per 100 g cooked product. Macaroni has a high protein concentration of almost 6%, when corrected for its dry matter to compare it with potato the concentration is 3.3%, still well above that of potato (1.7% according to these three particular sources). The two cooked cereals have substantially lower potassium levels than the root and tuber crops and higher zinc levels but lack vitamin C and are relatively low in folate.

Potato flour from the samples reported by the various authors (Table 12) contains less moisture, so appears to be more hygroscopic. It contains more ash which is partly due to its high potassium content. Their carbohydrate concentrations are similar but potato tubers are richer in starch and also in fibre. Mixes of wheat and potato flours are used as a basis of dough for bread making (Yanez et al. 1981). Potato flour compared to that of wheat has more favourable concentrations of vitamin C, polyphenols, potassium and most minerals but contains much less calcium.

Table 12 Composition of potato and wheat flours (average values of Mu et al. 2017; Rahman et al. 2015; Anwaar et al. 2014)

Ingredient per 100 g	Potato flour	Wheat flour
Moisture g	6.0	12.0
Ash g	2.5	0.5
Carbohydrate	80	75
Starch g	75	60
Protein g	9	11
Fat g	1.0	0.7
Fibre g	5.6	0.6
Energy kJ	1500	1500
Vitamin C mg	13	0
Vitamin B3 mg	5	0.9
Polyphenol (Chlorogenic acid equivalents)	0.32	0.00
K mg	400	20
P mg	90	25
Ca mg	25	150
Fe, Mn, Zn, Cu	X typical value in potato flour	0.05X–0.5X Typical values in wheat flour are 1/20th to half that of potato flour

Composition of the Potato Tuber

Burgos et al. (2020) produced an extensive review ‘The Potato and Its Contribution to the Human Diet and Health’ where they concluded that the bio-availability (fraction of eaten nutrient that is available for utilisation) and the bio-accessibility (fraction absorbed by the guts) of potato is higher than that of other staple crops, among others wheat and beans. Their tuber contents described the range of concentrations reported by authors they reviewed and some general remarks from their review are summarised in Table 13. The health benefits of all compounds mentioned and elaborated at length by the authors are not reproduced here as many seem insufficiently underpinned by scientific literature. The variation in values in general is due to the genetic differences that exist among varieties, to the environment where the crop is grown and to the management practices the crop was subjected to, especially fertilisation and water supply. Potatoes are very high in vitamin C, high in B6, relatively low in protein compared to cereals although their lysine content complements that of cereals, and very low in lipids. The most prevalent mineral is potassium and its zinc and iron content is beneficial where these elements lack in societies and can be enhanced through biofortification. Besides vitamin C, the anti-oxidants such as phenolic compounds (phenolic acid), carotenoids in yellow fleshed tubers (lutein and zeaxanthin) and flavonoids (anthocyanins) in coloured fleshed tubers play a positive role of potato in diets (Lachman and Hamouz, 2005). The concentration of phenolic acids, chlorogenic acid being the main one, decreases when tubers are peeled before boiling. Losses are reduced when cooking time is diminished, made possible by a preceding low power microwaving (Barba et al. 2008). Glycoalkaloids are associated with negative health aspects but their concentrations in raw material can be kept below hazardous levels through choice of variety (choosing low level varieties), through crop management (avoiding exposure of tubers to light, and processing (Friedman, 2006; Friedman and Levin, 2009). In one study (Tajner-Czopek et al. 2014) it was found that peeling reduced TGA concentration by 50% and blanching and frying added another 47% reduction. High levels of the reducing sugars glucose and fructose (over 0.3% of dry matter with asparagine as precursor) give rise to the formation of excess acrylamide in the Maillard reaction, which according to one Canadian survey showed the highest levels in potato chips (up to 3700 mg/kg), in French fries (1900 mg/kg) but substantially lower in bread (Becalski et al. 2003). Too low, less than 0.1% on fresh matter basis is not wanted for products needing browning when heated such as roast potatoes and hash browns (Biedermann-Brem et al. 2003). Starch is the major component of tubers ranging from 16 to 23%. In general, when a tuber contains 21% dry matter of which 2% is protein, 1.5% fibre and 0.5% other substances, its starch concentration is 17%. The global consumption rate of potato tubers is about 90 g per day but in Europe and North America with 60 kg/p/year (processed included) the consumption is over 160 g/day but in some tropical highlands in Africa and South America where the crop represents a main staple with consumption up to between 300 to 800 g per day (de Haan et al. 2019), there the crop is the main deliverer of the daily energy requirement.

Table 13 Burgos et al. 2020. Range of contents of 100 g fresh weight raw and cooked tuber

Content	Range	Remarks
Energy kJ	403–517	Cooked potato has a relatively low energy content compared to rice and wheat. Frying triples or quadruples the energy content
Starch g	16–23	Consists of rapidly and slowly digesting starches and resistant (amylose mainly) starches. Retrogradation increases slow and resistant starches and reduces the glycaemic index (Bertoft and Blennow 2009)
Glucose + fructose mg	2.75–400	Reducing sugars with free asparagine cause formation of acrylamide at frying in the Maillard reaction
Protein g	1.76–2.95	Concentration of protein is low compared to that of rice and wheat but its biological value exceeds it. It is high in lysine and low in methionine and cysteine
Lipids g	0.1–0.5	Lipids concentration of starchy root and tuber crops is lower than that of endosperm containing crop with seed as harvestable parts
Dietary fibre g	1.8–2.1	The 2.1 g/100 g is of unpeeled tubers as the skin has a higher fibre concentration than the flesh. Wheat flour contains less fibre than potato flour (Table 13)
Potassium mg	150–1383	Potato tubers contain a variety of minerals of which potassium is most abundant, potato is an important source of this mineral. Iron and zinc concentrations vary much with cultivar and soil characteristics. These minerals being crucial for human health, the International Potato Center (CIP) is engaged in biofortification thereof through breeding for high concentrations
Magnesium mg	16–40	
Iron mg	0.29–0.69	
Zinc mg	0.29–0.48	
Phosphorus mg	42–120	
Vitamin C mg	7.8–20.6	Potato is relatively rich in vitamins C and B6. The vitamin C concentration varies with variety, site and tuber age and decreases during storage and in cooking. The vitamin B6 concentration is influenced by the environment but does not decrease much in storage and cooking
Vitamin B6 mg	0.299	
Chlorogenic acid mg	19–399	Most important phenolic acid for defence in plants and anti-oxidant in humans, its concentration varies much with variety and origin. The concentration decreases with cooking
Carotenoids μg	1290–1813 Yellow fleshed	Creamy fleshed tubers have about one tenth of the concentrations of the yellow fleshed ones. Lutein and zeaxanthin are stable in cooking, others much less
Anthocyanins mg	71–543 Dark purple ones	Light red fleshed have about one 10th of such flavonoid concentrations. These compounds are stable in cooking with stable concentrations
Glyco-alkaloids mg	0.7–18.7 mg	α-chaconine and α-solanine play a role in the defence against pests and disease. Have bitter taste and are toxic at high concentrations (Friedman 2015)

Starch is considered to consist of three fractions as far as its digestibility by the human intestines is concerned: a rapidly digested starch fraction (RDS, digested within 20 min), a slowly digested starch fraction (SDS, digested within 2 h) and resistant starch (RS) not digested but fermented in the colon. First cooking and then cooling leads to the retrogradation of the gelatinised starch thereby increasing the fraction of SDS and RS (Monro et al. 2009; Magallanes-Cruz et al. 2016; Cummings et al. 1996). Beside a source of energy and availability of this energy through variation in digestibility a third characteristic of potato starch matters: its glycaemic index (Venn and Green 2007; Ek et al. 2014). Potato tubers have a high fraction of RDS, so have a high glycaemic index (GI), but there are large varietal differences and retrogradation reduces the fraction of RDS in favour of SDS and RS fractions. The level of glucose increases after consumption of a carbohydrate, which not only depends on its GI but also on the amount of carbohydrate eaten, the glycaemic load. Taking this into consideration potato's glycaemic impact is considered to be low to medium (Lynch et al. 2007).

Composition of Cooked Tubers and Selected Products

The composition of fresh raw tubers is shown in Table 14. Their energy content is relatively modest when compared to other root and tuber crops (Tables 10 and 11) because potato has the lowest concentration of solids of which carbohydrates represent the majority. Depending on variety and means of cooking tubers loose or gain some water which is reflected in the dry matter concentration. Loosing water at frying and adding oil leads to the high dry matter concentration and energy density of French fries. Dehydrated products chuño and flour have still higher energy contents, but after reconstitution with water the resulting meal ingredient in this respect resembles boiled tubers. Sugars hardly contribute to the carbohydrate and energy content but fructose and glucose when exceeding 0.3 g /100 g in the Maillard reaction are responsible for the formation of acrylamide. The carbohydrate/protein ratio is not unfavourable for potato, when alone responsible for the daily energy supply, the amount of protein is also close to the daily requirement. Potato is a valuable source of dietary fibre of which the highest concentration is in the skin.

Potato tubers contain low concentrations of fat, but fatty acids play a role in the gelatinisation process and glycoalkaloids are present in very low concentrations and should not exceed levels considered harmful for humans. Raw potatoes contain as much vitamin C as citrus fruits but about half is lost at cooking. The contribution of potato to the supply of potassium, phosphorus and iron is substantial but the tuber is low in calcium.

Composition of Selected Potato Dishes

Tubers boiled in their skin contain about the same concentration of nutrient as raw tubers with the exception of vitamin C of which about half is lost (Woolfe 1987). Table 15 shows average values from two sources of energy and nutrients in five potato dishes boiled or baked in skin, boiled peeled, prepared mash and French fries from a quick-service restaurant. The energy content of the first three dishes increases more

Table 14 Composition potato tuber uncooked, (m)g per 100 g average value of four sources (USDA 2015; Chandraseka and Kumar 2016; Woolfe 1987; Burgos 2020), cooked processed: data from Woolfe 1987 (citing Finglas and Faulks 1984; Watt and Meryll 1975; Paul and Southgate 1978; Collazos et al. 1974)

Composition	Raw	Boiled peeled	French fries	Chuño negro	Flour	Remarks
Energy (kJ)	335	301	1165	1393	1231	Relatively low energy content leads to positive balance of micronutrients (Gibson and Kurilich 2013)
Dry matter (g)	22.1	18.6	54.1	85.9	79.4	Starch mainly, has specific density higher than water; processors use this routinely (Haase 2003)
Carbohydrates (g)	16.9	16.8	36.7	79,4	73.2	Native starch, modified and derivatives made of potato (Singh 2016) and cassava starches
Total sugars (g)	0.65					Increase during storage at low temperatures (Amjad et al. 2020), cold sweetening
Reducing sugars (g)	0.20					When exceeding 0.3% risk of acrylamide formation at frying (Muttucumaru et al. 2019)
Protein (patatin) (g)	1.90	1.7	4.1			Well balanced protein:carbohydrate ratio (Woolfe 1987)
Fibre, dietary (g)	1.7	1.6	3.3	1.9	16.5	The skin contains 3 × more fibre than the flesh (Mullin and Smith 1991)
Lipids (g)	0,2	0.1	12.1		0.8	Concentrations are very low but they affect gelatinating properties (Ramadan 2016)
Glyco-alkaloids (mg)	6					Countries and unions set upper limits for what is allowed in food (e.g., CONTAM 2020)
Ash (g)	1.0	0.7	1.8	2.3		Dominant mineral is potassium. Up to 50% of the ash (e.g., this table)
Vitamin C (mg)	18	9	10	2	12	About half is lost at cooking, boiling, less at blanching or microwaving (Lee et al. 2018)
Potassium mg	400	280	720	920		Most dominant is potassium in ash of tubers and products 40–45% (this table)
Calcium mg	9	6	15	44	89	Tubers are low in Ca, processors are interested in enrichment (Tiwari et al. 2018)
Iron mg	0.45	0.5	1.1	0.9	2.4	Potato iron is soluble and its uptake is enhanced by ascorbic acid (Fairweather-Tait 1983)
Phosphorus mg	60	38	92	203	220	Potato's phytate concentration is low favouring Zn and Fe solubility and uptake (Camire et al. 2009)

Table 15 Nutrient composition of 100 g potato dishes, values provided by EUFIC (2021) from FSA (2002) and FCNT (2008) sources

	Boiled potatoes, in skins	Boiled potatoes, peeled	Baked potatoes, in skin	Mashed potatoes, with milk (7 g) and butter (5 g)	French fries, retail from burger outlet
Energy (kJ)	277	323	357	437	1167
Protein (g)	1.4	1.8	2.6	1.8	3.3
Carbohydrates (g)	15.4	17.0	17.9	15.5	34.0
Fat (g)	0.3	0.1	0.1	4.3	15.5
Fibre (g)	1.5	1.2	3.1	1.1	2.1
Potassium (mg)	460	280	547	260	650
Iron (mg)	1.6	0.4	0.9	0.4	1.0
Vitamin B1 (mg)	0.13	0.18	0.11	0.16	0.08
Vitamin B6 (mg)	0.33	0.33	0.23	0.30	0.36
Folate (μg)	19	19	44	24	31
Vitamin C (mg)	9	6	14	8	4

than proportional to the carbohydrate concentration which is explained that there is variation among samples taken from varied sources. To do it correctly the same raw material (tubers) should have been subjected to different means of preparation. The trends, however, are clear. Mashed potatoes contain 15.5% dry matter but the 4.3% of fat contributes substantially to the energy content. French fries with 34% carbohydrates and 15.5% fat contain 1167 kJ per 100 g which is more than four times that of boiled tuber in its skin. With the dry matter concentration increasing, and proteins representing about 10% of the dry matter, the remainder fibre and minerals, the protein concentration is highest in French fries and lowest in tubers boiled in their skin. Fat is only present in substantial quantities where added in milk and butter for mash and in frying fat or oil in French fries. Peels contain more fibre than flesh so peeled tubers have a low fibre concentration only fallen behind by a mash where tuber substance is diluted. Loss of water from tubers when making French fries causes the increase in their carbohydrate and fibre concentrations. Potassium (and iron) losses through leaching are substantial when tubers are peeled and boiled, or as is the case with French fries, blanched before frying. Vitamin B1 (thiamin) and B6 (pyridoxal) concentrations seem linked to the concentration of carbohydrates except for French fries so frying reduces their concentrations. Vitamin C (ascorbic acid) which is quite water-soluble is lost in boiling and blanching and apparently exacerbated at frying.

Table 16 besides peeled, boiled and French fries reported in Table 16, from another source, also shows the composition of raw skin-on tubers, flour and chips. Clearly, other samples and analysis methods were used to produce the data in Table 17 than for those in Table 16. For boiled peeled most data are within the same range for both sources but the UEFIC data showed double the folate concentration and half the vitamin C concentration compared to the FDC data. Vitamin concentrations, especially those of vitamin C, depend to a great extent on variety and on tuber age as the concentration diminishes during storage (Galani et al. 2017). The dehydrated potato product, its flour only, contains about 6% water against 80% in

Table 16 Composition of 100 g potato dishes, values provided by FDC (2021)

Nutrient	Unit	Unpeeled raw	Flour	Peeled boiled	French fries	Chips
Water	g	79.25	6.2	72.1	43.19	1.86
Energy	kJ	322	1493	365	1214	2234
Protein	g	2.05	6.9	1.87	3.49	6.39
Total lipid (fat)	g	0.1	0.43	0.14	14.04	33.98
Ash	g	1.11	4.24	0.92	1.90	
Carbohydrate, by difference	g	17.49	83.1	20.45	37.2	53.83
Total dietary fibre	g	2.1	5.9	1.4	3.9	3.1
Total sugars	g	0.82	3.52	1.61	0.28	0.33
Sucrose	g	0.17	0.40	0.19		
Glucose (dextrose)	g	0.31	0.44	0.37		
Fructose	g	0.26	0.34	0.30		
Starch	g	15.29	72.65			
Calcium, Ca	mg	12	65	5	17	21
Iron, Fe	mg	0.81	1.38	0.34	0.91	1.28
Magnesium, Mg	mg	23	65	24	29	63
Phosphorus, P	mg	56	1001	48	124	153
Potassium, K	mg	425	535	372	545	1196
Sodium, Na	mg	6	55	4	357	527
Zinc, Zn	mg	0.35	0.54	0.28	0.51	1.09
Copper, Cu	mg	0.11	0.197	0.188	0.112	0.234
Manganese, Mn	mg	0.153	0.313	0.138		
Selenium, Se	µg	0.4	1.1	0.3	0.4	2.5
Vitamin C, total ascorbic acid	mg	19.4	3.8	12.1	13.3	21.6
Thiamin B1	mg	0.081	0.228	0.106	0.11	0.213
Riboflavin B2	mg	0.038	0.051	0.020	0.057	0.088
Niacin B3	mg	1.033	3.507	1.439	2.564	4.762
Pantothenic acid B5	mg	0.295	0.474	0.520	0.522	
Vitamin B6	mg	0.298	0.769	0.299	0.184	2.0
Folate, total B9	µg	15	25	10	15	29
Carotene, beta	µg	1	6	8		0

the raw material tubers which explains the high energy density of flour, 4.6 × that of the tubers it is derived from. The carbohydrate:protein ratio is 8.5 in tubers and 12 in flour so in making flour some protein is lost. The protein concentration in raw and boiled tubers is of the same order, but with decreasing water content from boiled to French fries to chips, the protein concentration increases with carbohydrate:protein ratios of respectively 10.6 and 8.4. Potato hardly contains lipids so the high concentrations in French fries and chips originate from the oil they were fried in. The carbohydrate concentration of the products is a result of dehydration and is inversely correlated to its percentage of water but this is not so for fibre of which much is lost in peeling, blanching and frying. The bulk of the sugars in the tubers is represented by the reducing sugars glucose and fructose with low concentrations so not of much nutritive value. Recording by the industry is of interest as too high concentrations contribute to the dark colouration of products in the Maillard reaction upon frying.

The concentration of minerals is well maintained in flour where concentrations of about five times that of the raw tubers indicate that upon reconstitution the mash will have a similar concentration as the starting material. This is more or less valid for calcium, magnesium, phosphorus, sodium, copper and selenium but iron, potassium and zinc are partly leached during the production of flour. Boiled potatoes have similar mineral concentrations as intact tubers (the difference for calcium is not accounted for) and blanching and frying in general lead to some losses of most minerals because the increase in their levels is less than proportional to their dry matter concentration. The sodium concentration of the fried products is higher by far than the contribution of the starting material so this mineral was added when manufacturing them.

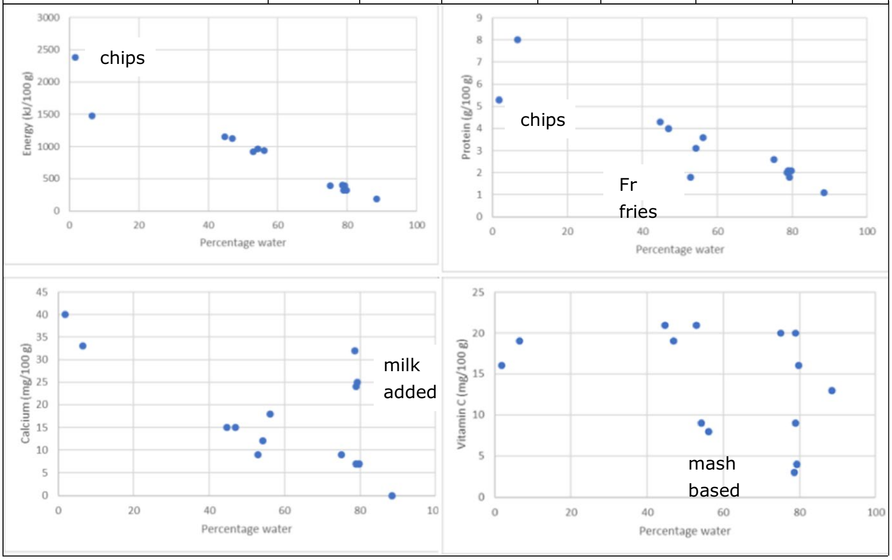
The concentrations of vitamins in the raw tubers and boiled tubers are of the same magnitude except for vitamin C which went from 19 to 12 mg/100 g. Except for thiamin, niacin and beta-carotene that maintain themselves, all other vitamins are strongly reduced in the process of making flour. The fried product shows the same tendency as the boiled tubers but because of a loss of water, losses have taken place for all but least so for vitamin B.

The data in Table 15 were compiled by analyses of samples from supermarkets and restaurants, so with different starting materials. The raw material originated from tubers of different varieties, from different sites where soil, weather and management practices were not the same. Survey 3 (Haverkort et al. 2022c) demonstrates how these factors influence not only yield and dry matter concentration but also all other quality characteristics of the harvested crop. Jimenez et al. (2015) purchased tubers of six varieties from different growers in the same Argentinian Andean valley in the same growing season and subjected them simultaneously to the same treatments (refrigerated storage, peeling, cooking and frying). The energy, protein, ash and carbohydrate of raw tubers were strongly correlated with the dry matter concentration that ranged from 17 to 27%, the fibre concentration range independent from the dry matter concentration between 1.9 and 3.3%. Boiling the tubers in the skin hardly affected the parameter values of the raw ones. Upon frying, the dry matter concentration on average increased from 20 to 40% and the values of the raw tubers more or less doubled. The vitamin C concentration, independent of the dry matter concentration, ranged between 11 and 29 mg per 100 g of which between 14 and 55% was lost when boiled in the skin and between 28 and 64% was lost when boiled upon peeling, both not correlated with the initial concentration in the raw tubers. These figures are indicative of the importance of employing the same starting material when comparing the influence of means of preparation on losses of nutrients and where not done so to treat the data with wariness.

Table 17 gives data on the presence of water, energy and five constituents in raw tubers and 13 manufactured products. The table also shows the correlations of four constituents with the water content in 100 g. The energy content correlates well with the inverse of the percentage water in the product with the exception of chips because of their high-fat concentration of close to 40%. The protein concentration also negatively correlates well with the water content of the product with some fried products as outliers because there, the potato substance is diluted with

Table 17 Composition of raw tubers and 13 potato dishes (PotatoUSA 2021)

Product type	Water%	Energy (kJ)	Protein (g)	Fat (g)	Carbo-hydrate (g)	Calcium (mg)	Vitamin C (mg)
Raw potato	78.9	319	2.1	0.1	17.1	7	20
Baked in skin	75.1	391	2.6	0.1	21.1	9	20
Boiled in skin	79.8	319	2.1	0.1	17.1	7	16
French fried	44.7	1151	4.3	13.2	36.0	15	21
Fried from raw	46.9	1126	4.0	14.2	36.2	15	19
Shreds dehydrated-rehydrated	54.2	962	3.1	11.7	29.1	12	9
Mash+milk+fat	78.9	395	2.1	4.3	12.3	24	9
Canned solids+liquids	88.5	185	1.1	0.2	9.8	0	13
Mash granules+water+milk+fat	78.6	403	2.0	3.6	14.4	32	3
Frozen cooked hash browned	56.1	941	3.6	11.5	29.0	18	8
Frozen French fried heated	52.9	924	1.8	8.4	33.7	9	21
Frozen mashed heated	79.3	391	1.8	2.8	15.7	25	4
Potato chips	1.8	2386	5.3	39.8	50.0	40	16
Potato flour	6.6	1474	8.0	0.8	79.9	33	19



fat. The calcium concentration also shows a few outliers because milk was added there. The vitamin C concentration is not correlated with the dry matter concentration; the 20 mg/100 raw and boiled in the skin is reduced somewhat upon peeling but the mash-based products have a very low retention of vitamin C.

Health Claims and Influence of Processing

Where the crop plays a role as a staple, its most important attribute is delivering energy (Table 18) to the human body through respiration releasing carbohydroxide and water, an inverted process from photosynthesis at the cost of absorbed solar

Table 18 Health benefits of tuber components (mainly based on four reviews: Zaheer and Akhtar 2016; Chandrasekara and Kumar 2016; Camire et al. 2009; Burgos et al. 2020)

Category	Compounds	Claim	Sources cited
Starches	Rapidly digested starch	Delivers energy	Fernandes et al. 2005
	Slowly digesting starch	Lowers glycaemic index, against obesity; increases satiety	Miao et al. 2015 Perry and Ying 2016
	Resistant starch	Anti-tumor, hypoglycaemic	Sajilata et al. 2006
Dietary fibre	Lignin and non-lignin	Reduces cholesterol levels, protects against acrylamide	Lazarov and Werman 1996 Dobrowolski et al. 2012
Lipids	Esterified fatty acids	Beneficial nutrients	Gibson and Kurilich 2013
Glycoalkaloids	α-chaconine α-solanine	Anti-biotic, reduces tumor growth	Friedman 2006, 2015
Protein	Patatin (amino acids) Potato Juice Protein Concentrate	Abundance of key amino acids (lysine and threonine), high biological value (comparable to eggs)	Camire et al. 2009 Kowalczewski et al. 2019
Anti-oxidants	Phenolics, chlorogenic acids (in yellow flesh)	Gut health, bacteria promotion	Mills et al., 2005
	Flavonoids (anthocyanins, in red and purple flesh)	Removes free radicals, enhances efficiency of vitamin C	Townsend and Tew 2004 Han et al. 2007
	Carotenoids (lutein, zeatin)	In yellow-fleshed tubers	Packer 1995; Tapeiro et al. 2004
Vitamins	Vitamin C	Anti-oxidant, against heart disease, cancer	Bates 1997; McGill et al. 2013
	Vitamin B complex (B6 pyroxidine especially)	Metabolism, brain function	Kennedy 2016
Minerals	Zinc Iron Calcium Phosphorus Potassium	Co-factor in enzymes Prevents anaemia Blood pressure, bone health Nucleic acid component, bone health Lowers blood pressure	Tapeiro and Tew 2003 Abbaspour et al. 2014 Harvard 2021 HealthLine 2021 He and MacGregor 2008

energy. The bulk of the starch in potato consists of readily available branched amylopectin chains with a larger area for molecular interaction for digestion than the linear structure of more abundant amylose. Native, unmodified starches are organised in granules of different sizes and consist of glucose polymers. Upon digestion, they are hydrolysed to end up as glucose molecules ready to be respired and deliver energy. Starches (Englyst et al. 1992) can be distinguished in rapidly digested (RDS), slowly digested (SDR) and resistant (RS) starches. Magallanes-Cruz et al. (2016) reviewing the influence of starch structure on its digestibility called SDR and RS 'neutraceutical starch fractions' because of their low or absent glycaemic index (GI) and their contribution to avoiding obesity; RS, moreover, contributes to a healthy gut biota (Keenan et al. 2015).

Dietary fibres, roughage, from cell walls play similar roles as RS (Cui and Robert 2009). Emsland (2021) on its website claims that potato fibre through its three-dimensional network as a natural food additive ingredient for meat, bakery and snacks enriches dietary fibre content, reduces carbs and fat, so calories, it easily binds oil and water and improves texture and structure. Fresh potato tubers offer a reduction of the carbohydrates per gram of tuber consumed (hence also the glycaemic (GI) and satiety indices) through a reduction of the dry matter concentration. Potato products (not so much cereal products) through an enhancement of dietary fibre and resistant starches following retrogradation reduce the GI, especially when accompanied by fat, protein and fibre.

Potato glycoalcaloids when present in low concentrations have positive health effects and also its lipids are considered beneficial. King and Slavin (2013) reported that besides digestibility of patatin, its composition of amino acids determines its quality as the presence of lysine, methionine, threonine, and tryptophan are considered essential for humans and the required levels of all four are exceeded by potato. So potato protein is highly appreciated where cereals do not meet the required lysine concentration. However, the levels of the amino acids cysteine and methionine, both containing sulphur, are lower in potatoes than in cereals.

All tubers contain vitamin C at effective concentrations and especially tubers with coloured flesh contain substantial amounts of other anti-oxidants, phenolics and flavonoids. B-vitamins also occur in such concentrations as to contribute substantially to the needed daily intake. The most relevant minerals are tabled; potato can remediate zinc and iron deficiencies in a population, especially when fortified.

Decker and Ferruzzi (2013) reviewed potential innovations to reduce the energy content of fried products in view of the image of French fries and chips as being responsible for obesity through a reduction of fat uptake and increasing the concentration of resistant starch. They used data of the USDA (2011) National Nutrient Database showing 0.10 total fat of which 0.03 g/100 g saturated fat in raw, boiled, baked and microwaved tubers, 4.7 and 0.9 g/100 in par-fried French fries, 17.1 and 4.0 g/100 in fried French fries and 34.6 and 11.0 g/100 g in chips. The resistant starch concentration is 69% in raw tubers and varies between 1.2 and 10.4% in finished products (Garcia-Alonso and Goti 2008). Draining water before frying and draining oil upon frying assisted by centrifuging reduces the fat concentration of products. When frying, water in tuber tissue is replaced by oil, diminishing water loss is realised by measures such as vacuum frying at a lower temperature than at ambient air pressure; certain batters containing proteins or modified cellulose reduce water loss and fat uptake and less oil is needed when frying with infrared radiation through the controlled dynamic radiant frying (CDRF) technique that combines evaporation of water with the formation of a brown crust. Reducing fat also alters the organoleptic properties of fried products as fat is a lubricant for chewing and swallowing so is not a desired trait of all consumers. Of the resistant starches entrapped, ungelatinised and retrograded, only the latter is manipulatable in processing through cooling and even more so by freezing upon gelatination with an increase from 3 to 10% of all starch in the products. Concentrations of minerals and vitamins in the finished products stem from the raw material, its variety and site and, according to Decker and Ferruzzi (2013), is not much influenced by adaptation of processing techniques.

Quantification of the Nutrients Domain

Information of the effort of condensing the nutrients domain expressed in Tables 10–18 is abbreviated in the heatmap of Table 19 where 11 classes of potato products and 3 non-potato classes of products figure with 11 attributes being their concentrations of nutrients. Where products were not mentioned in the tables of the previous section the concentrations were deduced from indirect evidence such as the proportion of potato and cooling after heating (for retrogradation).

With a mean score of 2.1, rice has the lowest one for lacking vitamin C, calcium and potassium. Gratins, a kind of diluted tuber, also have a low mean score. Chips score highest (4.0) with only very low scores for retrograded starch and antioxidant

Table 19 Heat map of classes of 14 products and with 11 concentrations of nutrients as attributes. For blanc cells, no data are supplied in Tables 10–18

High			Low
	a	Starch	
	b	Resistant starch	
	c	Oil	
	d	Protein	
	e	Fibre	
	f	Vitamin C	

High			Low
	g	Antioxidants	
	h	Calcium	
	i	Potassium	
	j	Zinc	
	k	Iron	

Number	Product classes	A	b	c	d	e	f	g	h	i	j	k	Av.
1	Frozen French fries												3.6
2	Frozen formed mash												2.9
3	Frozen formed shreds												3.3
4	Baked tubers												3.1
5	Blanched chilled												2.6
6	Frozen baked gratins												2.2
7	Vegetable/potato dishes												2.5
8	Chips												4.0
9	Stackable chips												2.6
10	Extruded snacks												2.5
11	Flour of potato												2.8
12	Brown rice cooked												2.1
13	Macaroni cooked												2.6
14	Cassava cooked												3.0
Average		3.1	3.3	3.1	3.5	3.1	2.8	1.8	2.4	2.5	2.9	2.8	2.8

concentrations. French fries contain more water than chips so in general have lower concentrations (3.6) but partly make up for this through a relatively high score for its retrograded starch concentration formed upon cooling after blanching.

The lowest mean value of an attribute averaged over the 14 products is for antioxidants, 1.8, with only macaroni having a very high concentration. The low value for the potato vegetable mixtures arises from the probably unjust assumption that the vegetables in the mixture contain no antioxidants. All the other concentrations diverge little from 3 so here the red and green concentrations cross against each other.

From the dendrogram (not shown) of the products and attributes based on the heatmap of Table 19, it readily becomes clear that chips are standing alone and the rest of the products are divided into two clusters. One consists of products containing moisture and the other one with the dry products plus rice, macaroni and cassava. The clustering of the concentrations seems arbitrary.

Perspectives Domain

Formulation of the Domain

The expansion of the potato processing industry in Europe and North America is flattening with the markets getting nearer to saturation. New plants are largely aimed at exporting to the countries where the industry is just starting (such as China) or where potato is not available for large-scale processing (for example Indonesia). Chips are produced in countries where the raw material is available, albeit at relatively high costs, which are acceptable for making chips as the proportion of the costs of the tubers in the finished product is relatively modest. Where no tubers are sourced locally, the raw material is imported. In China, India and Brazil, manufacturing of French fries started this century and is likely to follow the trend of Europe and North America in the past century. The outlooks of the different classes of consumers in this domain, so opportunities for the manufacturers, are not about the global expansion of the industry, nor on technological innovations, but focus on concerns and desires surrounding products for consumers.

Condensation of the Perspectives Domain

Mainstream potato food products are made in large quantities from conventionally grown tubers to satisfy the convenience requirements of most cooks. Consumers, however, from their perspective, increasingly desire food that for them has added value for health, conviction or organisational reasons. Enhancing the zinc, iron (Singh et al. 2021a, b) and vitamin A concentrations through breeding or at processing are examples that benefit populations where such nutriments lack in foodstuffs with deficiencies in populations as a consequence. Similarly, adding a vegetable component broadens the presence of desired components from the health, colour and taste points of view. Also, the shape may vary by three-dimensional printing of mash (Martínez-Monzó et al. 2019) before frying or serving into new shapes.

Sodium reduction (Kongstad and Giacalone, 2020) and replacers (Foodinsight 2022) such as lemon juice and cayenne pepper and acrylamide-free products (Lacy and Huffman 2016) and low-fat are examples of a desired reduction of a food component up to a complete absence such as gluten-free. Some consumers become more demanding, the traditionalists preferring the products that were and adventure-seeking the ones to come. Generic food labelling, besides the conventional label showing energy, fat, carbohydrates and salt content, is coming up, such as the Nutriscore first launched in France and now gradually spreading. Specific new products with more fibre, resistant starch and protein (potato milk, sports drinks) are preferred by various consumers for different reasons. Vegetarians want to be assured that no animal products are present in any additive and are likely to consume more French fries when more restaurants serve meat replacements (Linchpinseo 2022). Consumers have opinions on how the tubers are produced, preferring locally grown and/or organic and/or with demonstrated low land, water and energy (CO_2) footprints. Homes without kitchens want the food delivered hot and crispy or ready to place in the oven-microwave or buy it at a nearby vending machine. Table 20 lists and illustrates these perspectives and shows the attributes which the processing industry has to take into account when altering current or making new products. Is it easily doable, soon or late, will it be a niche or a major market, a regional or a global market, is it a necessity or just interest, is it a threat or an opportunity, will the cost be high or low, does it require innovation or just adaptation, will start-ups or the major companies expand and finally are regulators going to enforce a particular development?

Quantification of the Perspectives Domain

The 21 classes of outlooks and their attributes are scored with values from 1 (dark red) to 5 (dark green) as is shown in the heatmap of Table 21. A high score signifies that the industry is favoured when the perspectives of the consumers are easily and rapidly attained at low costs with a large market share with new products where the manufacturers take the initiative. Threats are specific consumer demands, competition and regulations, their absence leads to a high score as it also favours the industry. Regulations, however, when delivering a level playing field, may also be perceived as an advantage. The table clearly demonstrates, with average scores of 3.5, that realising food-to-food, implementing the Nutriscore and Catering for vegetarians and the kitchen-less consumers are most feasible for the processing industry. Fortifying products, satisfying specific consumers, fair trade and local for local are most difficult to meet.

Clustering with the aid of a dendrogram reveals the twins fair trade and local for local, which is meaningful as fair trade is easiest realised in a local setting. Fibre and protein are close twins, as they both when enhanced in food improve its quality for those benefitting from it. Demanding customers are associated with those aspiring to delivery at home. Low-salt and gluten-free are twins for logical reasons and the Nutriscore stands alone, which reflects that it is not an outlook of a group of consumers but an initiative of regulators.

Table 20 Outlooks various consumers have and a brief explanation of classes and appropriate attributes

Outlook class	Description of some instances	Attributes
Biofortification	Added zinc, iron, vitamin A	*Attainability*: ability to satisfy the desire of the consumer
Food-to-food fortification	Vegetable added to formed and flour	*Distance in future*: early or late moment in the future to realise
Personalised nutrition	For groups (elderly, halal) or persons	*Market share*: likelihood of becoming a major global market or a substantial regional market
Printing dish components	Mash from flour in designs	*Desire*: degree it is experienced as a need
Low-sodium	Low salt or salt replacers	*Threat:* for the conventional industry (or opportunity)
Low bruise, acrylamide	GM: avoidance undesired compounds	*Costs*: to make desired products
Gluten-free	Tubers contain no gluten, additives idem	*Initiative*: with consumers or with the industry
Demanding consumer	Ranging from tradition to adventure	*Newness*: need to make new products or adapt current ones
Nutriscore	Food labelled with health score	*Opportunity* for start-ups to jump in
Low-fat	High fat has risk of overweight	*Regulation*: chance that governments intervene with legislation
Potato milk	Vegetarian and low fat	
Vegetarian, vegan	Food additives and meat replacement	
Fibre, resistant starch	Low energy and enhances gut biota	
Protein enhancement	Enhanced patatin	
Organic production	Raw grown devoid of chemicals	
Low footprint	Efficient use of energy, land and water	
Fairtrade	Sourcing from smallholders	
Local for local	Outlet deploying locally grown raw	
At-home delivery	Fried products hot and crispy at home	
Homes without kitchens	Products heated in oven-microwave	
Fried products machine	French fries fried in vending machine	

Table 21 Heatmap of 21 classes of outlooks of consumers and 11 attributes regarding the consequences for the processing industry

High value			Low value
	a	Attainability (easy = high value of score)	
	b	Expected future to upscale (soon = high score)	
	c	Global market share expected	
	d	Regional market share expected	
	e	Necessity for certain consumers (great is a low score)	
	f	Opportunity	
	g	Low costs for industry	
	h	Initiative with processing industry	
	i	Newness	
	j	Competition from start-ups (much = low score)	
	k	Chance of enforcement by regulation (great is low score)	

	Class of outlooks	a	b	c	d	e	f	g	h	i	j	k	Av.
1	Biofortification												2.5
2	Food-to-food												3.5
3	Personalised												2.5
4	Printing												2.8
5	Low-sodium												3.5
6	Low acrylamide												3.1
7	Gluten-free												3.3
8	Demanding												2.6
9	Nutriscore												3.5
10	Low-fat (light)												3.1
11	Potato milk												2.9
12	Vegetarian												3.5
13	Fibre												3.2
14	Protein												3.2
15	Organic												2.8
16	Low footprint												3.2
17	Fairtrade												2.3
18	Local for local												2.5
19	Delivered												3.3
20	Kitchen-less												3.5
21	Vending machine												2.8
	Average	3.6	2.8	2.9	4.0	2.2	3.0	3.0	2.7	3.2	2.4	3.6	

Deliberations and Conclusions

Research Question About Potato Dishes

Some 175 potato dishes are listed in this survey but this is of course the top of the iceberg only. Anyone familiar with potato as a meal component looking at this list likely is able to add a few, and especially add sub-dishes with baked potato coming in varieties such as slitting and hollowing and a great number of fillings, stews and stamppot come with an array of potato-vegetable-meat combinations and gratins with numerous options for the sauce in the potato slices. So the list can be extended on the one hand but may also be condensed to boil down to only thirteen dishes with similar features. Dishes are soups, boiled tubers, mashes, fried to various degrees of crispiness, formed or shaped such as hash browns and patties and a few more including baked. Exactly these features were picked up by the potato processing industry and marketed in retail and food outlets and used by cooks in kitchens for convenience and to extend their diversity of plates. Home preparations with products are cooking stews where freeze or drum dried products are used as ingredient, for Jacket potatoes made in the oven, grill or microwave prebaked products are bought, for pan-frying pre-sauteed tuber cuts exist, for deep frying French fries and formed products and some dishes are complete like kugel, pancakes, gratins and scalloped potatoes ready to fry and bake. The available snacks are ready to eat but prepared from different semi-raw material (raw slices, dough and pellets) in various ways (frying, oven heating, popping, expanding) resulting in different products. Fibre for low-carb diets and protein as sports supplements are products not normally found in kitchens but serve as diet supplements. From this summary, the versatility of potato-derived products becomes apparent, the range of dishes and snacks and the variety in preparing them from an array of bought and processed ingredients.

Research Question About Sensory Perceptions

The typical potato taste from (non)volatile and alkaloid compounds is diminished compared to cooked tubers when producing mash from flour but intensifies with decreased water concentration going from boiled tubers to French fries to chips. The mouth feel following tuber texture and its elements such as consistency, dryness and mealiness are altered when producing mash (softer, moister and finer than tubers), French fries (firmer, drier and coarser) or chips (completely disintegrated, hard and dry). Processing tubers evidently can enhance aspects of flavour and texture and to lessen them, both, depending on product and use is advantageous or not. Besides the olfactory characteristics brought about by basic production operations and additives (influencing product quality) and flavouring (influencing product taste), the physical appearance plays a role in production and marketing. Products of the same category differ in size (long and short, thin and thick French fries), shape (straight or corrugated) and in colour (white and cream fleshed tubers, degree of browning and addition of colourants). Products vary in the number of shapes they are produced in with few variations in size for baked tubers and many shapes for French fries and extruded snacks. Flour as a rule contains no additives nor flavourings whereas French fries contain many of both. Individual particles, chunk and shapes vary in size with flour containing the smallest and baked tubers and gratins the largest. So it was shown that all basic senses are appealed upon when exposing and eating potato products and their dishes.

Research Question About Nutritive Value of Potato Products

The section on the condensation of the nutrients domain contains 10 tables: 1 on the conversion of nutrients into energy and the results for potato constituents. The following three tables compare potatoes with a few other crops or their products. A table is inserted with ranges of nutrient concentrations found in tubers with different backgrounds (crop variety, environment and management. The concentrations of tubers bought on the market in New Delhi grown in winter on irrigated clay soils in lowland Utter Pradesh differ considerably from those in Kigali grown in rainfed volcanic tropical highlands. Potato usually is served as a (side) dish so then the nutrient composition of a dish is relevant as is shown in the three tables with data of different origin and composition of dishes. The section concludes with a table demonstrating some health claims of some potato constituents.

Fat in prepared potato dishes has the highest energy density of 37 kJ per g, carbohydrates and protein have similar densities of 17 kJ/g and fibre the lowest, 8 kJ/g. So, obviously, chips with over 30% are the richest in energy and skin-on boiled or baked tubers without dressing have the lowest. With the lowest carbohydrate concentration of the five major root and tuber crops potato therefore also has the lowest energy density, almost half of that of cassava on crop fresh weight basis. Potato contains more protein than cassava but is lowest in calcium of the five crops and lets cassava go first concerning the vitamin C concentration. Of the other root and tuber crops, only sweet potato is processed into, e.g., frozen fried sweet potato among others in the USA and South Africa and cassava is a major raw material for starch production in countries like Thailand.

Besides energy from carbohydrates, mainly the concentrations of protein, lipids, dietary fibre, minerals especially calcium, phosphorus, iron and zinc and vitamins B and C are determinants of the quality of food. Potato has a lower dry matter and energy content than sweet potato, cassava, wheat (eaten as macaroni) and brown rice. Macaroni is highest in protein and lipids, sweet potato in sugars and fibre. The cereals are lower in calcium and magnesium but higher in zinc and iron concentrations than the root and tuber crops but contain no vitamin C and are low in folate.

Producing boiled or baked tubers either or not in the skin, French fries, various mashes, chuño, flour or chips strongly influences the nutrient composition. The energy content compared to boiled tubers up to quadruples in French fries and dehydrated products but upon reconstitution of dry products and powders these are brought back to the level of boiled tubers. Chips contain seven times more energy per 100 g than boiled tubers. Dry matter in tubers is around 20%, in fries 50% and around 80% in the dehydrated products. Comparison of 14 products (three of them non-potato: cooked rice, cassava and macaroni) with 11 nutrient concentrations showed that protein and starch concentration are the most frequent descriptors of most products and antioxidants least. Products are clustered more or less according to their dry matter concentration (degree of dilution) and concentrations of nutrients seemingly according to their solubility.

Research Question About Consumer Perspectives

Consumer perspectives concern health (fibre, minerals), convenience (at-home delivery), availability (vending machines), environment (footprints) and idealistic (fair trade, local-for-local) motives. The industry likely reacts by seizing opportunities through innovation and capturing a substantial market share, especially in currently saturated markets. Easily reachable goals for the industry are food-to-food enrichments, implementing food health lables and satisfying vegetarian and kitchenless consumers. Biofortification, fair trade and local-for-local production are met with much more exertion.

Table 22 Overview of the 4 domains figuring in this survey

Domain	Classes	Nr	Example of class	Main attributes	Nr	Example of attribute
Dishes	Dishes	13	French fries	Properties	10	Cooking temperature
Senses	Dishes	13	Mashed	Sensory perception	12	Crunchiness
Nutrients	Products	14	Baked tuber	Nutrient content	11	Vitamin C
Perspectives	Outlooks	21	Biofortification	Consequences	11	Competition
Total		61			44	

In conclusion, this paper reviews existing dishes worldwide and how the processing industry derived thereof products for kitchens and the food industry. The nutritive value of tubers and their products was explored. In general, the density of nutritive components of the products is correlated with their water content that decreases from blanched or baked, to frying French fries, chips and production of flour. Starch, minerals, some vitamins and anti-oxidants become less diluted and appear in higher concentrations in products than in the raw material they are derived from. The energy content increases more than proportional in fried products because of adhering oil that per unit weight almost has more than double the energy content of starch. Additives such as SAPP, batter and dextrin improve the flesh colour of French fries, their crispiness and staying hot time and give the golden hue. Flavouring creates a wide range of tastes of French fries and chips. Blanched and chilled products either or not mixed with vegetables are often supplied with sachets of seasoning to be spread on the product while preparing a dish in the kitchen as the seasoning effect would partly disappear when mixed with the chilled product. In this survey in five domains total 671 times a value was given to a class × attribute combination in 61 classes and 44 attributes (Table 22).

The Four-Tier Analysis proved instrumental in delimiting the three domains, dishes, senses and nutrients, of the super-domain nutrition. Boiling down a complex field per domain in tables, a single heatmap and a cluster hierarchy is an adequate approach in triangulation of data.

Declarations

Competing Interests P.C. Struik is editor-in-chief of Potato Research.

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