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On Processing Potato 2. Survey of Products, Processes and Operations in Manufacturing

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Abstract

In supermarkets in the Netherlands, well over 150 potato products are displayed. They can be distinguished by heating characteristics (boiled or fried), appearance (e.g., intact tuber pieces or formed hash browns), dehydrated (e.g., snacks and flour) and storage temperature (e.g., ambient and frozen). Fancier products (frozen formed versus chilled blanched) require more processes and operations in factories and are more expensive; consumers appreciate them because they offer more convenience. Heatmapping and hierarchical clustering were carried out twice within the domain of classes of products and their attributes. In a theoretical triangulation, consumers give high scores to low prices and a wide range of products, tastes and sizes where processors give these attributes a low score. Processes in factories include dehydration, heating, cooling and transformation. Examples of the latter are modification of starch to increase the range of applications in the food industry, forming of mash and shreds to produce croquettes and hash browns and expansion to make snacks. Processes require operations such as washing, cutting, blanching and packing. In total, between the arrival of the tubers at the gate and leaving as packed products to outlets, 66 operations are distinguished. French fries undergo some 30 operations and to produce flakes, 8 suffice. Heatmapping and hierarchical clustering differentiate a group of physical operations (with attributes associated with heating and cooling that require much energy) and mechanical ones (related to separation, grading, sorting for instance and size reduction of which shredding is an example that require little energy). The wide range of operations in large factories, reducing the moisture content and longtime storage at low temperatures,

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distinguishes potato from wheat that has fewer operations while increasing the moisture content in relatively small bakeries and the product, bread, stored for about one day in ambient conditions.

Keywords Dehydration · Heating · Modification · Supermarket · Theoretical triangulation · Transformation

Introduction: Inception and Research Questions

In shops, especially supermarkets in affluent societies, a wide variety of processed food products are found. The majority of products as far as shelf space is concerned, is based on the four main staple foods, wheat, corn, rice and potato. Wheat products (bread, cookies, pastries) dominate in most markets, and in Asian countries there is also emphasis on rice and in European and North American countries on potato. Potatoes, unlike most vegetables, need to be cooked before consumption, as its starch cannot be digested by non-ruminants such as humans (Narwojsz et al. 2020). When eaten raw, it is not affected by the stomach and upper intestines and in the colon its starch is fermented, producing gas leading to flatulence (Birt et al. 2013). When heated, the tubers, its cell walls and amyloplasts disintegrate, and the starch granules (Singh et al. 2005) absorb water, gelatinize and become digestible. In starch potato factories, all starch-related processes take place at low temperatures so the resulting native starch, and modifications thereof, need to be reconstituted with water and heated. Also freeze-dried products need to be boiled upon reconstitution with water.

Just one procedure prepares food from freshly harvested tubers, washing. It is often followed by peeling and cutting but not necessarily for all side-dishes. Subsequently, tubers or parts thereof are boiled in kitchens, on occasion mashed, fried or baked, and eaten as such. Deep frying potato cuts (French fries) is also one of the preparations in kitchens at homes, institutions and restaurants. Starch extraction at home is done only sporadically to make glue, but the industrial extraction already took place as of the middle of the nineteenth century (Haverkort et al. 2022). The processing industry delivers all products that cooks can prepare in the kitchen, dry ones including flour, chips and gnocchi, baked ones such as jacket potatoes and hasselbacks, blanched ones for instance baby potatoes and sliced ones packed or canned and fried ones including French fries, formed products and chips.

Cereals, notably wheat, rice and corn, when harvested contain about 15% moisture (Tahir et al. 2007) and to make an edible meal component, water needs to be added. With the tuber crop potato containing 80% water, adding water is not needed, heating suffices, although some water is used at blanching, boiling and steaming. Cereal starches are digestible without heating in water, whereas moist potato starch needs to be heated, which is another feature distinguishing these two sources of food. Table 1 shows the four main food crops, the operations needed to prepare a meal component from the main product and the by-products (Phetmanyseng et al. 2019; Liu et al. 2015; Rausch et al. 2019). Boiled potato and rice and bread are meal accompaniments whereas corn starch is an ingredient of sauces and soups, a thickener. The majority of potato tubers, globally, is purchased fresh from shops and markets and prepared in the kitchen. All cereals, rice and wheat and corn, however, are processed in factories

Table 1 Principle minimal factory and kitchen operations, besides cleaning, to produce food from the harvested crop

Crop	Factory operations	By-products	Main product	Basic operations to make a meal component
Potato				Boiling
Rice	Dry milling	Husk, bran, germ	White rice	Boiling
Wheat	Dry milling	Bran, embryo	Flour	Adding water and yeast, baking
Corn	Steeping, wet milling	Gluten, fibre, germ	Starch	Add hot water

(mills) and the products grain, flour or starch used as ingredients. All four crops can produce flour from ground whole kernels or boiled and dried tubers. But also pure starch is derived when protein and fibre are washed out. Of the four crops, the bulk of corn is processed into starch, of potato and wheat a considerable proportion and of rice a negligible part. This because, globally, corn starch is produced at the lowest costs and rice starch at the highest. Not all starches are readily soluble in water, nor applicable for a wide range of uses in the food industry. Therefore, they are subjected to a range of treatments, modifications.

Although no primary processing of potato is needed to make a basic side dish, the number of processes and underlying operations the tuber is subjected to in kitchens is considerable, as was shown in the first survey (Haverkort et al. 2022). The products in supermarkets have undergone many of these and some considerably more.

This survey seeks to capture the relevant subdomains with classes of products, classes of processes they went through, and the classes of operations that underlie the processes and their respective attributes. The latter are awarded a score as to the degree they apply to the classes and where possible through theoretical or environmental triangulation. Where the first survey (Haverkort et al. 2022) took the most important participants into account (growers, processors and cooks), this survey focuses on products available for cooks and the processes and operations that create them. To disentangle the myriad of products, processes and operations that helps elucidate the particular issues within the domain of potato-based food processing, the Four-Tier Analysis approach explained in Haverkort et al. (2022) is followed: domain description, completing classes and attributes through methodological triangulation, quantifying the latter followed by hierarchical clustering with the aid of dendrograms. Here follow the research questions that are put forward.

In supermarkets, many potatoes, potato products and potato-derived products are shelved at ambient, cold and freezing temperatures often of more brands and several weight classes. This demarcated domain of potato products in supermarkets has not been analyzed in detail through an inventory and description of its subclasses condensed to classes that have experienced similar processes with their descriptors. What information with relevance for subsequent research regarding processes and their underlying operations it yields is unknown to date.

Potato products on sale are moist (blanched and chilled) or dry (flour), still have some of the tuber structure intact (French fries) or not (gnocchi), some have been fried (chips) or never experienced any temperature above ambient (native starch). Some products are not for sale in supermarkets as they go to the food industry directly or are

an ingredient in potato-based food, such as granulate and modified starches. The questions arise which classes and subclasses of basic processes lay at the base of products and how to meaningfully classify and supply them with attributes in a delimited domain? Which intermediate products go to the food industry and what are their functionalities? Are there specific requirements and demands made on the tubers serving as raw material, do processes vary in use of water and energy and which processes require the product to be stored at below ambient temperatures?

Processes, such as dehydration leading to starch and frying to chips, involve many operations taking place in factories. Some products probably undergo few operations such as skin-on baked tubers, but of most products consumers have no idea what they went through. The domain of operations in potato processing plants with all classes of operations taking place and their descriptors, attributes, has not systematically been defined. Nor is it made visible which classes and subclasses of products undergo specific operations and for what purpose. A systematic allocation of attributes to operations in order to distinguish groups according to necessities such as, for example, heating or water use has not been carried out, so has not been judged on its merits.

The Domain of Potato Products on Sale in Supermarkets

Formulation of the Supermarket Domain

The small town Wageningen in the Netherlands of about 40,000 inhabitants has six supermarkets where mainly food is sold. The stylish ones contain a bakery, a butchery, a greengrocery and all have shelves with packed and canned food, fridge compartments with chilled food and frozen compartments with deep-frozen food. In December 2020 one particular supermarket, of the rather classy brand Jumbo, was visited and the potato products observed. The greengrocery department sells 13 fresh tuber products. The choices are waxy or floury tubers, general use or specific use for French fries preparation, ordinary or gourmet potatoes, conventional or organic or environment conscious, regularly sized or baby potatoes. This particular shop displayed the cultivar name (cv.) beside quality characteristics such as waxy, floury and for making French fries. Not all shops do this. The domain of potato products on the market here is limited to the products found in one supermarket thought to be representative of larger and smaller ones and situated in larger and smaller cities in developed and less developed markets, provided they have a cold chain: freezing and chilled compartments. Its list is expected to not exhaustedly represent the products made in many factories, on sale in many supermarkets. This single supermarket in the Netherlands is representative in a wider context as the range of products found there are similar in other settings. There, the range may be smaller or wider with less or more products within the same category (snacks for instance) and with different sizes and flavours.

The supermarket (Table 2) had 30 chilled products on display, 42 when considering that some products were sold at two different weights e.g. at 200 and 500 g. Chilled products appear as dishes in a tray, gratins, ready to place in the oven or microwave. Others appear in plastic bags loosely packed. Only few of the same quality characteristics as shown in the fresh tuber displays, appear in this department: waxy or floury and use as French fries or mash. No mention of the variety used is made. But other

Table 2 Potato products in a supermarket (Jumbo Supermarket at Wageningen, The Netherlands) on a single day in December 2020)

Nr	Type	Category	Description	Nr	Type	Category	Description
				76	**Formed**		Skin-on wedges
1	**Fresh**	Waxy	cv. Regina 5 kg	77			Mash
2			cv. Mozart 3 kg	78			Cubes
3		Organic	cv. Vitabelle 2 kg	79			Dices
4		French fries	cv. Alegria 5 kg	80		Aviko brand	Mini croquettes
5			cv. Alegria 2 kg	81			Bistro
6		Floury	cv. Milva, 3 kg	82			Rösti mini
7			cv. Milva, 1 kg	83			Rondjes
8		Waxy	cv. Loreley, 3 kg	84			Rösti mix
9			cv. Loreley, 1 kg	85			Rösti bacon/onion
10		Trade mark	Conscious 1 kg	86	**Dishes**	Jumbo Brand	Burgundian
11			Baby potatoes cv. Suzanne 0.5 kg	87			Netherlands
12			Red Gourmands cv Cherrie, 0.5 kg	88		Aviko brand	Swiss Rösti
13			Yellow Gourmands cv Lavie, 0.75 kg	89			Netherlands
	Chilled tray or bag			90			Greek
14		Casserole	Patates gyros	91			Gratin
15			Casserole Gratin				
16			Casserole hasselback	92	**Dry**	Gnocchi dumplings	..di patate. 500 g bag
17			Casserole Rosemary				
18		French fries	Air fryer fries	93		Gnocchi	.. di patate 500 g oven tart
19			Fryer fries	94	**Flour**	Maggi brand	Mash natural
20			Skin-on farmers' fries	95			Natural a la minute
21		Whole tubers	Oma (Grandmother)	96			Hotchpot (stew)
22			Waxy	97			Crème fraîche
23			Hotchpot (stew)	98		Jumbo brand	Natural
24			Floury	99			A la minute
25			Pan fry		**Snacks**		
26		Pan fry sections	Skin-on natural	100		Jumbo brand	Ribbed paprika 250 g (335 g)
27			Peeled natural	101			Ribbel natural 250 g, 335 g
28			Seasoned bell pepper	102			Sticks natural 150 g
29			Skin-on paprika	103			Sticks paprika 150
30			Skin-on curry	104			Undulated pepper /salt
31			Skin-on provençal	105			Undulated sweet chili 150
32		Discs	Small	106			Garlic
33			Large	107		Organic	

Table 2 (continued)

Nr	Type	Category	Description	Nr	Type	Category	Description
							Biologisch paprika 125
34			Section	108		Lays brand Super Chips	Natural 200/280 g
35			Ham and onion	109			Paprika 200/280 g
36			Duopack (2×350 g)	110			Ketchup 200/280 g
37		Cubes and baby tubers	Cubes	111			Jopiepatat 200/280
38			Natural 200 g, 500 g	112		Lays brand	Undulated natural 147 g
39			Bistro 200 g, 500 g	113			Bolognese 200/280
40			Gyro	114			Light 170 g
41			Burgundian	115			Sour cream
42			Pan fry fine cut	116			Cheese union
43			Texas barbeque	117			Strong Chili
44			Duopack 2×250 g				Strong hot chicken wings
45	**French fries**	Jumbo brand	Patates Frites 2 kg	118			Sensations Mexican pepper
				119	**Snacks**		Sensations Red sweet paprika
46			Patates Frites 1 kg	120			Sensations Japanese wasabi
47			Flemish fries	121		Enrico	Natural, paper bag 110 g
48			Super Cruncy	122			Spanish, paper bag
49			Oven	123			Cucharada (pringle type)
50			Ribbed	124			Cucharada paprika
51		Organic	Bio	125		Kettle	Sea salt 150 g
52		Aviko brand	Pommes frites 2 kg	126			Sea salt and pepper
53			Pommes frites 1 kg	127			Paprika
54			French fries 2 kg	128			Salt and vinegar
55			French fries 1 kg	129			Sweet chili
56			Flemish fries	130		Chio	Salt, kettel 150 g
57			Granny's	131		Tyrell	Furrows 150
58			Oven	132		Torres	Black truffle 40 g E 1.65
59			Crinkle fries	133			Iberian ham 40 g
60			Sunny fries	134		Croky brand	Paprika 125/270 g
61			Raspatat (Formed)	135			Bolognese 125/270 g
62		Beyer-lander brand	Rapid airfry	136			Super frites Paprika 150
63			Crinkle fries	137			

Table 2 (continued)

Nr	Type	Category	Description	Nr	Type	Category	Description
							Super frites Naturel 150
64			Strait no coating	138	**Stackable snacks**	Pringles 165 and 70 g tubes	Original, paprika, sour cream-onion, hot&spicy, roast beef, Texas bbq, flame, Cheese-onion, salt&vinegar
65			Strait with coating	146			
66		Lamb Weston brand	Rustic strait				
67			Ziggy crinkle				
68			Twister				
69	**Formed**	Jumbo brand	Small croquettes	147	**Baby food potato base in jars 120–300 g**	Olvarit	Beans, carrots, broccoli, pumpking, mixed (organic)
70			Wafers	151			
71			Roses	152		Hippo	Mushrooms, chicken
72			Balls	153			
73			Bistro balls	154		Nestlé	Pumpkin (organic)
74			Pom Duchesse	155		Jumbo	Spinach
75			Sections	157			Beans
							Carrot

characteristics are added: skin-on or not, whole tubers or parts thereof (slices, cubes, dices, French fries cut). The size of sections and slices are itemized and seasoning and spices added with reference to national tastes such as 'French bistros' and 'Burgundy' and 'Mexican barbeque'.

The assortment of French fries and related items consisted of 23 products of 4 different companies, one of them the private Jumbo label. Among them regular, crinkle, with and without coating and rapid air-fry. Of some products it is not readily obvious in what they differ from other ones such as 'Granny's' and 'Sunny'. Raspatats are French fries not made of cut tubers but of dough shaped as French fries cuts and battered. Their shape, bite and taste are very consistent.

The supermarket had 16 frozen formed potato products for sale, most of them private label and one brand. Croquettes being the most popular on offer, the rest consists of balls, wafer, patties, pomme duchesse, baby potatoes, look alike dices and cubes and rösti (hash browns). Frozen dishes with potato contain other vegetables such as carrots and bell peppers with mushrooms and ham (Burgundian) or potato sections with gyros pork, courgetti and bell pepper (Greek) and there are more. A gratin (Gratin Dauphinois) consists of thin tuber slices in cream and baked, this also is a readymade potato dish.

Dry potato dish ingredients registered in the inventory, numbering seven, were gnocchi and flour to prepare mash with options natural and à la minute (more soluble),

Table 3 Classes of products stored: 1) frozen only, 2) frozen and chilled, 3) chilled only, 4) ambient conditions

Class	Nr	Subclass	Description	Factory preparation
Cut, blanched and fried	2	Strait cut	Cuts of tubers of about 9 mm × 9 mm × 6 cm	Peeled tubers are cut into one of the many shapes, blanched at 70 °C for 5 min, dried, par-fried in oil at 170 °C and frozen at –18 °C. Kitchen: fry for 5 min at 180 °C
	1	Curly cut	Spiral shaped cuts 2.5 cm long, 1.5 diameter	
	1	Crinkle cut	Corrugated with dimensions of regular cut	
	1	MacFry	6 mm × 6 mm × 7 cm	
	2	Flemish cut	12 mm × 12 mm × 5 cm	
	1	Wedges	Wedge shaped 5 cm long, usually skin-on	
	1	Tater drums	Cylinder shaped 1.5 cm, diameter 2.5 cm length	
	1	Lattice cut	Basket weave pattern, roundish 4 cm diameter	
	2	Various	Dippers, shells, skins, shoestrings	
	1	Twister	Spiraled curls 2 cm diameter 3 cm long	
Cut, fried	4	Chips	Thin crispy slices, often flavoured	(Un)peeled thin slices, fried
Dough formed, fried	1	Patties	5 cm diameter potato cookies	Dough from fresh mash or flour, formed, fried
	2	Croquettes	Battered round 2.5 cm diameter, 5 cm long	
	1	French fries	Dough shaped in French fries regular cut	
	1	Whipped	Puffed dough (wheat flour added) with egg	
Shredded tuber, shaped and fried	1	Cake	As hash brown but with dough instead of shreds	Forms are made from potato mash: mashed boiled tubers or from reconstituted flakes, seasoned, shaped to form the desired product, par-fried and frozen same as French fries
		Pancake	Dough ingredient of flatter and larger hash brown	
	1	Hash brown	2 cm thick patty shaped seasoned shreds	
	1	Rösti	Pan sized hash brown, if not same as hash brown	
	1	Pancake	Thinner and larger than hash brown	
		Tater tots	Small hash browns with corn starch binder (’53)	
Baked	1	Jacket P	Whole tuber	Shredded, diced or chopped tuber parts shapes 1.5 cm thick of various shapes
	1	Stuffed	Whole tuber slit, filled	
	2	Rissole	Small tubers 3 cm diameter boiled pre-pan-fried	
	2	Au gratin	Slices, in tray (casserole) ready to bake	
	1	Halve shells	Unpeeled whole 6 cm tubers, flesh scooped	Oven prepared whole or scooped or sliced tubers, some with filling. Gratin contains slices in a creamy sauce, rissole is pan fried
	2	Mash	Mashed boiled tuber (parts)	

Table 3 (continued)

Class	Nr	Subclass	Description	Factory preparation
	1	Dices	IQF 2 cm×2 cm dices (Individually Quick Frozen)	
	1	Shreds	IQF 2 mm×2 mm×4 cm shreds	
	2	Dumplings	2.5 cm dough balls with wheat, egg (gnocchi, knödel)	
Blanched or boiled	4	Tubers	Baby tubers (if cut: scooped with a melon baller)	Whole or scooped
	2	French fries	Various cuts	Shapes see fried above
	3	Slices	About 6 mm thick slices par-boiled	Cutting, blanching
	4	Liquid dish	Potato-based soup, sauce or stew, pasteurized	Food industry, babyfood
	4	Slices	About 6 mm thick dry slices	Peeled and cut
	4	Cubes	About 1.5 cm^3 dry cubes	Partly for food industry
	4	Flakes	Flour, flakes, granules ready to (drum)dry	Peeled, blanched
	4	Snacks	(stackable), (popped), (expanded) chips	Potato for taste and structure
Dried	4	Slices	About 6 mm thick dry slices	Air dried in cottage industry
	4	Cubes	2 cm×2 cm	Freeze dried under vacuum
	4	Pellets	Various shapes and sizes	Par-boiled, mashed dried
	4	Expanded	Snacks from pellets	Expansion upon frying, baking
	4	Powders	Flakes, flour, granulate	Drum drying

ingredients added (crème fraîche) or with a more original potato mouth feel with granulate added.

The shelves displayed 52 dry snacks (chips) (56 when adding products available in two weight classes) of 11 brands. Of the 52 chips products 9 consisted of stackable chips of a single brand, Pringles. The snacks differ in shape so as to the size of the slices, their shape flat, ribbed or undulated and slices (majority), similar stackable copies or thin sticks. The seasoning is the most varied characteristic, 19 different combinations, with 'natural' dominant, only salt added, and typical for the Netherlands market 'paprika' (bell pepper) is very popular. 'Organic' (1 out of 37) is a trait of snacks and so is 'light' (also 1 out of 37). The latter contains about 20% fat rather than the 30% in regular products. The package also is a feature wherein products are distinguished by large and small bags and made of polythene (the majority) or of paper. How chips are prepared also shows on the wrapping in a continuous process on a frying belt, dominant, or in batches, so-called kettle chips and made of intact tubers. More than the other products the prices per kg showed variation with an over tenfold difference between the private label Jumbo, natural, large bag of 335 g at €3.37 per kg, versus the Torres brand 'Black truffle' taste in a 40 g bag priced at €41.25 per kg. Formed and stackable made of potato dough there were 10 (14 if varying sizes are distinguished) different products of a single brand: Pringles. Extruded and expanded

potato-based products numbered 16 distinguished by brand, taste and shape (heart, bear, rings sticks, screw).

This supermarket did not sell canned tubers nor potato soups but there was one jar of 390 ml containing a potato-based sauce for use in the oven (Aardappel Anders) and 11 types of potato containing baby food in jars of 4 brands, 2 of them also offering organic products.

Potato products found in supermarkets can be distinguished in frozen, chilled and stored under ambient conditions. The bulk of manufactured potato food products globally is frozen to -18 °C at the factory, distributed refrigerated, exposed in freezers in shops and at home or restaurants placed in freezers again or thawed and prepared. Tables 3 shows the five main categories of frozen products; they are:

- Cut products in a variety of shapes and size (French Fries Machine 2021; Couture 2017) either or not battered and par-fried. In the kitchen the par-fried potato parts are fried for a few minutes and served. Also air-fry and oven heating preparations exist whereby the product contains more fat than the non-oven ones but the final dish less. The bulk of products is made of white or cream flesh coloured tubers but niche products are made of coloured tubers (Lachman et al. 2016).
- Boiled products, mashed to fit the product (stiffer for balls than for puffs), seasoned and shaped in various forms. Kitchen preparation possibilities as with fried potato cuts with pan-frying added for potato pancake (Kiremko 2021a, b; McCain 2021; LambWeston, 2021).
- Shredded or julienned products, often onion added for rösti and hash browns (Kaczay 2016), type and proportion of binder varies. Preparation in kitchens as for cut and for formed products with a larger proportion pan fried.
- Baked products (Potatoes USA 2021) consist of raw tubers whole, slit, scooped or baked in a sauce (gratin) or pre-pan-fried. In the kitchen these products are baked whether or not with a filling, baked in an aluminum casserole in which they are usually commercialized or pan fried in case of rissole.
- Heated tuber parts in watery environments at near or boiling temperatures (blanching, steaming, boiling) yield an array of products, mashed among them. Blanching followed by IQF (individually quick freezing) produces frozen ingredients for dishes in kitchens. Dumplings consist of dough with non-potato ingredients prepared by boiling in water in kitchens (Lisinska and Leszczynski 1989; Maine Potatoes 2021; Zaheer and Akhtar 2014).

Many frozen products are also available in a chilled version. These are not frozen to -18˚C but cooled to 4˚C. Table 3 also summarizes these product categories and subcategories. Some products are packed in plastic in vacuum to evacuate all oxygen, pasteurized (Peng et al. 2017) at 96 ˚C degrees and can then be stored for weeks or sterilized at 100 °C or higher (Ramesh 2003) and can then be stored for many months. Vacuum packing is only done with products that allow compression without losing shape such as French fries and then usually only packed in larger than household packages of 1 or 2 kg but in 5 kg or larger packs for outlets. Display in vacuum is not considered attractive, so most products are loosely packed in plastic bags with print in controlled atmosphere, nitrogen only. For formed products chilling is not possible as when they are unfrozen they lose their form. Some formed products are placed in plastic or aluminum trays to be baked in the oven. Potatoes in

cans or glass jars need no chilling as they are sterilized, similarly to potato dishes (soups for instance) sold in tins or bags.

Fully dehydrated potato products (Table 3) need no refrigeration nor cooling and can be stored for many months in controlled atmosphere, such as potato snacks where the oil risks to become rancid. Also light is detrimental for the quality of the oil, reason why these products outside the cottage industry environment are packed in aluminum coated polyethene bags, or the stackable ones in tins or cartons. Dehydrated slices, cubes and flour contain no oil nor seasonings and are packed with ambient air in permeable paper and carton packages.

Quantification of the Supermarket Domain

The eight potato product categories found in supermarkets (fresh tubers, chilled tubers and parts, frozen French fries, formed products, dishes, dehydrated, snacks and baked tubers) are listed in Table 4 against 11 attributes. The range or variety of products within a category is the first one, the variety being low with only two flour types but high for chips.

Table 4 Heatmap of 8 classes of potato derived food products in supermarkets with 11 attributes values from the consumer point of view (top) and **from the processors point of view (bottom)**

High value			Low value
	a	**Range of products**	
	b	Price range	
	c	Shelf temperature	
	d	**Weight range of package**	
	e	**Number of different shapes**	
	f	**Number of different tastes**	
	g	Fanciness	
	h	Convenience	
	i	Stacking density	
	j	Number of operations in factory (Table 9)	
	k	**Price per unit weight**	

			a	b	c	d	e	f	g	h	i	j	k	Av.
CONSUMER	Fresh	1												2.6
	Chilled	2												3.1
	French fries	3												2.8
	Formed	4												2.9
	Dishes*	5												2.7
	Dry**	6												1.9
	Snacks***	7												4.0
	Baked tubers	8												1.6
	Average of 1-8		3.3	2.8	2.8	3.3	2.5	2.6	2.6	4.0	2.3		1.0	2.7
PROCESSOR	**Fresh**	**1**												**2.5**
	Chilled	**2**												**2.7**
	French fries	**3**												**2.8**
	Formed	**4**												**3.1**
	Dishes*	**5**												**4.3**
	Dry**	**6**												**4.0**
	Snacks***	**7**												**2.9**
	Baked tubers	**8**												**3.0**
	Average of 1-8		**2.8**	**2.8**	**2.8**	**2.8**	**3.5**	**3.4**	**3.1**	**3.5**	**2.3**	**3.5**	**4.5**	**3.2**

*Gratins, soups, sauces, stews, baby-food
**Flakes, flour
***Fried, baked, popped chips and expanded snacks

Similarly products have an average price level per kilogram and a range of prices around it, of weight of the packages in which shelved, and of tastes as there are many in chips and other snacks with a wide variety of flavours available. A product is more fancy if not eaten at a regular basis but as a more exceptional treat consumed at memorable occasions when guest are there, or in a slow service restaurant. A product is more convenient when it takes more time to prepare a dish in the kitchen based on purchased fresh tubers. Vacuum packed chilled slices are a most densely packed, chips most loosely. The number of manufacturing operations a product goes through is derived from Table 12. The appreciation of the attributes of the products depends on the point of view from the user or the producer. Consumers want a choice from many products, processers are more interested in a narrower range as it requires less finetuning of operations and packaging in the plant. For some attributes, user and producer have opposite aims as is shown in Table 4: array, weight, numbers of shapes and tastes. Here the values in Table 4, lower part, are mirrored around the average value 3. One exception is made to flipping the scores: both consumers and processors prefer low prices of fresh tubers for cooks to prepare and for processors to use as raw material. Consumers have no knowledge nor interest in the factory operations so this column is left blank in Table 4.

Snacks have the highest average values of the attributes with only a low score for density of packing as they are loosely stacked and a medium value for fanciness, often consumed routinely. Flour is dry and stored at room temperature and is densely packed, only two high scores with the other attributes receiving low scores only. The average value of an attribute over all product classes is highest for convenience. Only fresh tubers and flour receive a low score as it takes time to make a substantial dish from them. Only a few products, powders and dishes are densely packed hence a low score for this attribute.

When looking at the products from processors' point of view some inversions take place. For them the class of dry products emerges with the highest score for which they have to accept the consumer low scores for price range and convenience. The average value for snacks drops from 4.4 to 2.9, comparable to fresh tubers from the consumers point of view. Dishes are also valued by processors for their added value with one disadvantage: they have to be shelved frozen. Where consumers are willing to pay, are accepting the price, processors, in this exercise are thought to go for higher prices for all products preferably with fewer shapes, flavour and operations in the plants.

The whole tubers (fresh and baked) are in one cluster, dry and dishes also are a cluster of two (twins) and frozen fries and formed are twins in the same cluster as fried snacks. The theoretical triangulation did not change the hierarchy of the products but it did affect that of the attributes. With the consumer point of view, fanciness and price range are twins and product range, shape and taste are a triplet, and the other attributes are clustered less noticeably. From the processors outlook shelf life stands alone beside the twins concerning package range and density and the triplet price and ranges of products and shapes.

The Domain of Basic Processes in Transformation of Tubers

Formulation of the Processes Domain

The raw material, tubers entering the processing facility, is grown on fields planted with seed tubers and supplied with nutrients, biocides, irrigation water and harvested

Table 5 Processes (operations), intermediate and finished products in starch and food production, finished products in **bold**

Product	Process	Process	Primary product	Processes	Secondary Product	Processes	Pack & store of finished product	**Tertiary product**
Raw product (Tubers delivered to factory)	Washing[a] grading[b] sorting[c] peeling[d] cutting[e] shredding[f]	Rasping	Pulped tubers	Filtering	Raw fibre	**Feed for ruminants**		
						Cleaning	**Clean fibre, food grade**	
				Concentration	Starch	Washing, refining, drying	Bulk for food, ambient	**Native starch**
					Fruit water	Heating	Bulk for feed ambient	**Denaturalized protein (feed)**
						Chromatography	Bulk for food, ambient	**Natural protein (food)**
		Blanching	Blanched Tuber (parts)	Grinding Drying	Flakes	Grinding	Paper bag, ambient	**Potato flour**
				Cooling	Cuts	Gentle mashing	Paper bag, ambient	**Granulate**
				Chilling	**Chilled tuber**		Plastic bag, chilled	
				Par-frying	**French fries**		Plastic bag, frozen, chilled	
				Mashing	Mash	Forming	Loosely packed, frozen	**Formed products**
						Rolling Baking	Stacked in can	**Stackable chips**
				Canning	**Canned tubers**		Pasteurized, ambient	
				Julienning	Shreds	Forming, frying	Loosely packed, frozen	**Hash browns**
		Frying	**Chips**				Loose, CA	
		Baking	**Jacket potato**				In tray, chilled or frozen	
		Drying	**Dried tuber parts**				Loosely packed ambient conditions	
		Hydro-lysing	Sugars	Fermentation	Beer	Distillation	Bottled	**Vodka**

a: for all tubers entering factories
b: not for starch production
c: not for starch production
d: not for skin-on products (baked tubers)
e: not for whole tuber products (baby tubers, baked tubers)
f: only for raw shreds based products (certain hash brown recipes)

Table 6 Overview of basic processes in transformation of tubers (little detail only for farm, factory preparations and kitchen processes)

Crop	Raw	Process		Operations	Product	In kitchen
Growing	Potato tubers as raw material washed, peeled, cut	Dehydration	Extraction	Grinding tubers with water, starch settles at the bottom, air dried	Starch	Add water and heat
			Drying	Tuber cut in slices dried in air (cottage: in sun and wind)	Dried	
			Freezing	Whole tubers traditionally making chuño, industrial tuber parts, cubes, freeze-dried	Dried	
Handling			Heating	Boiling, mashing, hot air drying in heated drums, scraped off and ground	Flour	
			Granulating	Gentle boiling and mashing yields intact potato cells (granules)	Granules	
		Conversion	Modification	Native starch subjected to chemical and physical treatments as ingredient for the food industry	Starch	Industry
			Forming	Tubers are boiled, ground to a mash and formed, subsequently fried	Forms	Fry
Storing			Pelleting	Flour is pelletized and dried as intermediate product	Pellets	Industry
			Fermentation	Fermentation to make beer, if subsequently distilled, vodka	Alcohol	Ready
		Blanching	Drying	Blanched tuber parts are dried at the surface to prepare for frying	Par-boiled	Fry
			Chilling	Blanched parts are supplied with anti-oxidant and chilled, storable for a week	Chilled	Cook
Transport			Canning	Blanched (baby) tubers are sterilized and canned	Canned	Cook
		Frying	Expanding	Expansion of pellets by deep frying	Snack	Ready
			Crisping	Deep frying thin slices until all water has evaporated	Snack	
			Frying fries	Deep frying of blanched and dried tuber parts	French fries	
		Baking	Of tuber	Unpeeled, skin-on tuber	Jacket	Bake
			Of slices	Chip sized thin slices	Snack	Ready
			Of dough	Of stackable chips size	Snack	

(Haverkort, 2018). In case of organic farming, nutrients and biocides are not synthetic. For starch production, all tubers suit, but for other destinations they are graded to meet the specifications of the product: small round tubers for chips and large long ones for French fries. Sorting consists of removal of unsuitable tubers presenting defects such as green skins and cuts. Washing is done on-farm in some instances for crisping potatoes, but then they cannot be stored and are delivered to the factory directly. The majority of tubers is stored for one to many months with temperature, relative humidity and concentration of carbon dioxide regulated. Transport to the factory takes place under frost-free conditions and for very long hauls in warm condition they are refrigerated. Once arrived at the processing plant, tubers are destoned and washed and subjected to subsequent operations. Many operations are mechanical such as washing, conveying and cutting and take place at ambient temperatures, but, especially for the food industry, operations involve heating. Processing potato is making products such as illustrated in the first section of this survey through a sequence of operations demonstrated in the third section. In this second section the principle classes of processes (dehydration, conversion, blanching, frying and baking) are underpinned by the required operations and the resulting main classes of products supplied with operations related attributes.

Condensation of the Processes Domain

Table 5 gives an overview of the processes and (intermediate) products implied in starch (BeMiller and Whistler 2009) and food production from washed tubers. The three main components of starch potato tubers upon grinding are starch, protein and fibre and their destination is revealed. The lowest value is the fibre, usually silage and destined as feed for cows. Some facilities extract food grade fibre used in the food industry to give structure, bite, feel and satiety to food products (Potato Fibre 2021). A higher value is attributed to the denaturalized protein that can be used as feed for non-ruminants such as pigs but is not marketable for human consumption. Denaturalization (Ralet and Guéguen 2000) takes place by heating the fruit water, the liquid remaining after settling of the starch at the bottom of the vessel. Extracting protein in cool conditions by means of chromatography yields natural protein, comparable to that in whey, which is used in the food industry (Lokra et al. 2008). The bulk of the dry matter of tubers is starch, considered native before modification into products for the food and non-food industry. Starch also is the main component of the final food products beside about 75% water in chilled and baked tubers, 50% in French fries and formed products; chips and potato pellet based fried snacks contain about 30% vegetable oil.

To produce food of potato tubers, all components (starch, protein, fibre) end up in the finished products. Rather than grinding, tubers upon peeling and cutting initially remain completely or partially intact. Subsequent procedures among others imply baking, boiling, blanching, julienning (and forming), fermentation resulting in (intermediate) products such as flakes (Cui et al. 2018), French fries and formed products (PotatoPro 2021), made into chips (Van Loon 2005), baked (AHDB 2021), dried (Doymaz 2012), canned baby tubers (PS, 2021), or turned into alcohol (Xu et al. 2016).

Table 6 presents the five main processes dehydration, conversion, blanching, frying and baking subdivided by the temperature and moisture conditions in which the process takes place or in case of blanching the subsequent action.

Dehydration is aimed at obtaining raw material as intermediate for further purposes (starch production, forming), to render the tuber storable under ambient conditions tubers or parts dried. Freeze drying (Setiady et al. 2009) in factories is sped up when done in vacuum. Traditionally in the Andes at 4000 m above sea level at 60% of atmospheric pressure present at sea level is equally advantageous.

The only digestible dehydrated product not needing heating upon reconstitution is flour resulting from drying boiled tubers. Granules (Olson and Harrington 1955) are digestible but not dissolvable in cold water.

Five processes involve conversion of an intermediate potato product: native starch, potato mash, flour, pellets and alcohol. Modification of native starch into substances destined for the food and non-food industry is done by physical means such as heating and chemically among other with the aid of enzymes. Modified starches are raw material for the food and non-food industry. Forming consists of shaping potato dough, mash, of which the result is ready to deep fry as e.g. croquettes. Pelleting consists of compressing and heating moist flour followed by forcing through a shaped opening and cutting the extruded string at regular intervals resulting in molded pellets with a great variety of shapes.

Blanching and boiling comprise of heating small tubers or tuber parts whereby the starch gelatinizes and becomes digestible but not fully cooked. Blanching is followed by drying to prepare tuber parts for frying, for chilling or for canning. Upon frying pellets expand, the result is seasoned and marketed as snacks. Thin potato slices deep fried until the sizzling stops also yields snacks and frying larger blanched chunks produces French fries.

In factories, intermediate and final products are transported and further subjected to the mechanical processes washing, peeling, cutting, grinding, grating, forming, extruding and packing. Physical processes are par-boiling to make flour and chilled products, par-frying of French fries and formed products, baking of jacket potato, distillation for vodka, heating and drum drying for flakes, vacuuming and sublimation for freeze drying, cooling for chilling and freezing. Chemical processes are fermentation for beer and some means of modification of starch.

The processes involving dehydration yield dry products such as starch, flour and dry tubers or parts thereof. If it takes place at ambient temperatures in a wet process (grinding and washing) to produce potato starch (Grommers and van der Krogt 2009), or in a dry process whereby potato parts, slices usually placed on a mesh, are subjected to sun and wind and air dried in a cottage industry fashion in developing markets (Haverkort 2018), the product needs to be reconstituted with water and heated for the starch to gelatinize (Wilson et al. 2002). The same holds for the products of freeze drying (Fellows 2017; Wang et al. 2010), lyophilization or cryodesiccation, which are three concepts of dehydration using sublimation, moving from a solid to a gaseous stage without going through a liquid phase. The procedure is hastened by reduced air pressure (vacuum) and creates dehydrated potato parts that still retain much of the original structure. Flour is produced from blanched or boiled tubers (Willard 1959; Cui et al. 2018) and does not necessarily need heating, although in kitchen preparation reconstituted flour or its formed products are baked, boiled or fried before being served.

Conversion of an intermediate potato product is modification in case of starch (Singh et al. 2016), forming of potato-based dough or mash (Kiremko 2021a, b) and

pelletizing followed by expansion (Van der Sman and Broeze 2013). Native starch is modified by physical (temperature, pressure) and chemical (enzymatic, hydrolyzation) means into products with a wider range of applications than that of native starch. These include nonfood uses such as in the paper industry and food uses for bakeries, e.g. thickeners of sauces and soup. Mashed potato or dough made of potato flour is (trans)formed into shapes (forms), croquettes and dauphins. Airy, crunchy expanded snacks are manufactured by heating pellets in oil or hot air (Willard 1976). Pellets are made by forcing potato dough through a forming opening (extrusion) whereupon the die cut string is interrupted by knife at regular intervals and the result dried, packed and shipped to extruded snack fabricators. The gelatinized starch matrix contains entrapped moisture that upon heating produces steam which makes the pellet to swell into a light snack. Another way of preparing snacks based on extruded moist dough is baking (Onwulata et al. 2001; Avebe 2021a, b).

Blanching or par-boiling for a few minutes at temperatures varying from 75 to 100 °C yields tubers or parts (slices, dices, strips, French fries) that are vacuum packed and chilled (Gormly and Walshe 1999), canned and pasteurized (Singh and Rattan 2014) or par-fried upon dewatering and frozen (Pedreschi 2012).

Frying in oil at temperatures between 150 and 180 °C until some water has evaporated and the surface has a light crust yields par-fried French fries (Pedreschi 2012) that subsequently are packed, frozen or chilled. Frying thin slices until all water has evaporated yields chips, when prepared from thin slices of dough they form stackable chips (Spoonuniversity 2021).

Baking tubers and parts is in hot air of over 150 °C only with no water or oil added. Whole tubers upon baking yield (Decker and Ferruzzi 2013) baked or jacket potato or, with many incisions, hasselback potato. Baking thin slices at high temperature until all water is evaporated produces low fat chips (Tuta and Palazoğlu 2017). Stackable chips, (cookies, Pringles®) are made of potato dough with some corn starch added, rolled to a thin sheet and from which chips shapes are punched and baked (if not fried) (Spoonuniversity 2021).

Modification of Potato Starches

Non-food uses of potato starch include adhesives for wall paper and paper bags and for sizing and finishing of textile. For application of derivatives of potato starch in food as an ingredient of an ingredient several methods exist to modify the native starch (Sharma 2012). Physical modification that involves high temperatures, pressures or sounds; chemical modification where the native starch is subjected to reactants and genetic modification whereby the plant's genome is altered to produce a particular type of starch (Table 7).

Gelatinization of starch (Kadam et al. 2015) by adding water and heating is the same process as cooking raw tubers before extraction of starch. Starch becomes soluble when heated with moisture (gelatinizes) because of loss of its crystalline structure. When consumed before cooling down and given time to retrograde, its digestion properties have not altered. With retrogradation (Wang et al. 2015) however, part of the digestible gelatinized starch recrystallizes, resists digestion: resistant starch. The industry uses such starch among other as coating of drugs. Pre-gelatinization consist of a gelatinization step (heating after adding water), whereupon the water is removed again. This

Table 7 Physical, chemical and genetic modification aimed at increasing the suitability of potato starch for multi-purposes After Singh et al. (2016)

Treatment	Treatment (starch subjected to)	Properties of resulting modified starch	Applications in food
Physical modification			
Gelatinization	High moisture, high temperature	Water uptake possible De-crystallization	Rendering starch digestible for humans
Pre-gelatinization	Cooking, drying, grinding	Cold water soluble	Food processing, thickening agent
Retrogradation	Cooling after gelatinization	Partial recrystallization	Resistant starch (e.g. drug coating)
HTM (hydro-thermal-modification)	Low moisture (25%) at above gelatinization temperature	Increased gelatinization, temperature and viscosity	Food processing (e.g. baking powder)
Annealing	High moisture (50%), below gelatinization temperature	More thermostable, gelatinization only at increased temperature	Food industry
UHP, US	Ultra-high pressure, ultrasound	Distortion of crystals, facilitates gelatinization	Food industry
Pyroconversion (acid pyrolysis)	Heating (after hydro-chloric acidification)	Dextrin, shorter chains than starch	Enhances crispiness, used in batter
Chemical modification			
Hydrolysis	Acid or enzymes	Reduced polymer size	Baking industry
Oxidation/bleaching	For instance peroxide or hypochlorite	Reduced polymer size Bleached starch E1403	Emulsifier (in e.g. batter), coating of products
Etherification	Propylene oxide	Easily soluble starch	Instant starch (soup, dessert)
Esterification	Acetate, phosphate	Esterified potato starch	Partial replacement wheat flour
Cross linking	Phosphoryl chloride or other cross-binding agent links various starch chains	Cross linked starch, resists high and low temperatures better than native starch	Canned food, batter (crispiness)
Genetic modification			
Gene silencing	Antisense downregulation	E.g. amylose free ‘waxy’ potato (amylopectin potato)	Clear sticky paste used in food industry

process is not unlike preparing flakes from intact tuber parts. The resulting powder is soluble in cold water.

Two processes exist that stabilize the starch and increase future temperatures at which the starch gelatinizes and, with it, increases the viscosity of the result. One is withholding adequate moisture at above gelatinizing temperatures (HTM) and the other one (annealing; Hoover and Vasanthan 1994) withholding sufficiently high temperatures at above gelatinizing moisture content. Subjecting native starch to gelatinizing temperatures (between 70 and 100 °C) at low moisture conditions (25% rather than 80% in raw tubers) is a hydro-thermal modification (HTM; Vermeylen et al. 2006). Annealing (Muhrbecka 1996) takes place at a moisture content of above 50% sufficient for gelatinating but at around 50 °C too low for effective gelatinating to take place. HTM and annealing products find their way in food ingredients such as baking powder (Singh et al. 2016). Preparing food ingredients from native potato starch through mechanical processes, ultra-high pressure (Kim et al. 2012) and ultrasound (UHP, US) makes for more convenient gelatinization, faster and at lower temperatures. Dextrin is produced from starch by heating (pyroconversion) facilitated by first acidifying it (BeMiller and Whistler 2009). It has many non-food applications and is used as a batter ingredient as it produces crispier products when deep frying.

Table 7 also shows several chemical modification processes such as hydrolysis with an acid (Absar et al. 2009) whereby long chains are broken down to smaller ones to make native starch suitable as ingredient in the baking industry. Reducing the size of the starch chains is also achieved through oxidation with an agent that delivers oxygen such as peroxide. The resulting bleached starch is employed as an emulsifier to make batter and coatings. Etherification produces a starch that easily dissolves in cold water to make soup or desserts and esterification changes potato starch such that it is comparable with wheat flour and can partly replace it for breadmaking and other applications. With cross-linking, the already long polymer chain of potato starch becomes heavier still, because the cross-binding agent links chains of different starch molecules that resist high temperatures.

Genetic modification does not modify the starch in a factory, but in the potato plant. The production of amylose is downregulated through antisense in genetically modified plants yielding amylose free waxy amylopectin tubers (Hameed et al. 2018) that has a specific niche in the food industry because of its stickiness.

Functionality of Modified Starch, Flakes, Flour, Granulates and Protein

Dehydrated potato products and modified potato starch fulfill a range of functions wanted by snack manufacturers, the food industry, bakeries, institutions including among other hospitals and outlets such as restaurants (Table 8; after Potato USA 2021b,c).

Ground meat in balls and burgers benefit from potato products as they act as a binder to hold the meat particles together and as an extender so more finished product is made with the same amount of meat. Adding potato to wheat flour increases the yield of flour as potato absorbs more water. Flakes and granules alter the preparation properties as adding them to batter before frying produces a crispier crust than wheat flour when adding to liquids such as soups, broths and sauces they are also more effective than wheat flour and are less prone to forming lumps. Role in beautifying is evident when a potato mash decorates a casserole before baking and also the enhanced darker colour of

Table 8 Functionality of potato derived food ingredients. https://www.potatogoodness.com/wp-content/uploads/2019/08/Brochure-Dehy.pdf

	Use (societal)	Snack	Industry	Bakeries	Institutions	Outlets
Binding	Free starch and flour hold meat together in balls and burgers		x		x	x
Extending	Flour, flakes increase the volume of minced meat so less is needed					
Yielding	Dehydrates absorb more water than wheat flour so increase yields			x	x	x
Breading	Flakes yield more crispy texture at frying than wheat products		x		x	x
Thickening	Flakes and granules thicken sauces and soups without lumps		x		x	x
Unvarying	Flakes and granules as dough to make uniformly shaped chips	x	x		x	x
Decorating	Mash pressed through pastry tube to decorate casseroles					x
Colouring	Dried potato product enhance darker colour at baking		x	x	x	x
Enhancing	Flakes and granules in snacks enhance potato taste in products	x	x	x	x	x
Humidifying	Dehydrated potato in dough moisturizes so reduces staling of bread			x		
Texturing	Flakes in cakes provides more moist texture, provide softer bite	x	x	x	x	x
Formulating	Flakes, granules and flour replacing wheat make gluten free food	x	x	x	x	x

baked food is a visual aspect. Dehydrated potato products also influence the taste and mouth feel of food where a potato taste is required, where shelf life of bread is extended and cakes acquire a softer bite. Where a food stuff solely consists of potato ingredients it is formulated as gluten free fit for coeliac patients. Mash from powder, flakes rather than flour causes less lumps and as such is a nutriment that according to the information on the package also contains an emulsifier (mono- and di-glycerides), an acidulant (natrium citrate) and an anti-oxidant (sulfite).

Nielsen (2019) summarizes that modified starches are binders in snack coatings and noodles; they replace fat in sausages, also in French fries sauce where they act as a binder and give sauce a creamy, smooth texture. They have similar roles in crème fraîche, replacing animal derived products including vegetarian “cheese” and “meat”-balls. Potato starch products derived from waxy potatoes consisting of over 99% amylopectin, according to the producer (Avebe 2021b) achieves the same or better results with a smaller amount of ingredient. In nonfood modified potato starches are present in building material such as in tile adhesive to avoid gliding of the tile, in gypsum as a thickener and for making it more malleable, in yarn spinning to avoid breaking of the thread, in adhesives including paper adhesive tape and glue sticks, card board tubes such as toilet rolls, paper bags and layers of laminate. Potato starch based

polymers of anionic and cationic polymers act as a flocculation agent in water purification facilities.

Commercial food grade potato protein is isolated from fruit water (Table 5) containing native protein and purified through ion exchange bed or membrane adsorption chromatography (Schoenbeck et al. 2013) and dried. Different protein fractions have different functionalities such as no flocculation at low pH in sour sauces and texture requirements of the finished product. It is gluten free, halal, cosher, vegan and is a replacement of egg and whey protein (Avebe-protein 2021).

Quantification of the Processes Domain

The processes, products and their use shown in Tables 5, 6, 7, and 8 are summarized in the heatmap in Table 9 with as superclass products resulting from the basic principle processes and as classes, instances thereof. The least energy from fossil sources needed (none) is dehydration by wind and sun in the open. The energy need of other processes is closely related to the resulting dry matter concentration as it costs energy to evaporate water from tuber parts, the longer exposed to, the higher the temperature. As benchmark par-boiling of French fries was chosen, which takes place at boiling temperature for a few minutes after which the tuber parts are dried and fried. Similarly, par-boiling and baking is a matter of just heating and subsequent chilling or freezing. Canning increases the energy requirement, as making cans represents energy as well (Drew and Rhee 1980). French fries and formed products still contain a considerable amount of water, around 50%, which puts them in the same league as chilled and canned products. Drying and frying to very low water concentrations in powders and snacks involve most energy. When taking the energy embedded in the production of oil present in snacks, it would need another darker red colour. The more energy spent in the factory on making a product, usually the less energy it takes to prepare it in the kitchen. Snacks are ready to eat without spending any energy on them, boiled in the factory it only needs heating in the kitchen (chilled, canned) but reconstitution needs more time at high temperatures; only frying or baking French fries and formed products at over 170 °C use more energy. Once washed and cut, only washing starch involves considerable amounts of water, boiling, blanching and canning some, but all other processes hardly or not at all. In the kitchen, dehydrated products need most water to rehydrate and cook, chilled products only water that surrounds them for boiling (or nothing when fried, baked or casseroled). Some oil or fat is used in making formed products in a factory but more per unit when producing par-fried French fries or formed products such as hash browns, but none on par-boiled (blanched, canned) products. Baked snacks contain less fat than fried ones. Reconstitution of dehydrated products and cooking does not involve use of oil or fat unless made into casseroled or deep-fried dishes. When reconstitution with water of dried products and heating them is taken as a standard, consuming snacks is much more convenient, preparing (side) dishes from chilled tuber parts is somewhat more cumbersome and deep frying takes more time and equipment to heating the oil and frying to just the right colour.

Table 9 Heatmap of 20 classes of products and their 13 technology related attributes

Much	a	Cumulative energy need for processing	Little
Many	b	Temperature of process	Few
High	c	Cumulative water need for processing (after washing)	Low
	d	Oil use in the factory	
	e	Specificity and price of raw	
	f	Dry matter concentration	
	g	Use of product by the non-potato food industry	
	h	Maintenance of original structure and appearance	
	i	Recovery from raw (few side flows, wastes)	
	j	Number of operations by user to be able to use	
	k	Advantage large scale factory (low cottage industry potential)	
	l	Size of package	
	m	Need of cold chain	
	n	Number of factory operations	

Superclass	Class		a	b	c	d	e	f	g	h	i	j	k	l	m	n	Av.
Dehydrated products	Cold-wet extracted starch	1															3.2
	Cold-dried discs	2															2.1
	Freeze dried cuts	3															2.9
	Hot drum dried flour	4															3.1
Conversed products	Modified starches	5															3.7
	Formed, fried shapes	6															3.1
	Extruded, baked	7															2.8
	Pelletized, expanded, baked	8															2.7
	Fermented beer	9															1.7
	Distilled vodka	10															1.9
Blanched products	Par-boiled French fries	11															2.9
	Chilled cuts	12															3.2
	Canned tubers	13															3.1
Oil fried products	Chips	14															3.2
	Stackable chips	15															3.1
	Pellets expanded fried	16															3.0
	French fries (par fried)	17															3.5
Baked products	Jacket potato	18															2.9
	Baked chips	19															3.0
	Dough (cookies)	20															2.5
		Average	3.8	3.3	2.8	2.4	2.7	3.7	1.7	2.5	2.9	2.7	3.8	2.7	2.1	3.4	2.9

The raw material used is subjected to a varying array of requirements (Haverkort et al. 2022) the more (for chips) the more expensive, raw to produce starch is the cheapest. Starch production also has a high proportion of losses, side flows with low value such as feed. In a French fries factory almost all material is recovered and made into flakes when not suitable for the main finished product. A few of the attributes concern the user, such as the size of the package, the opportunities for multiple purposes in the kitchen and the need for a cold chain.

Table 9 displays the heatmap of the classes and the degree to which the attributes apply. Of all the products the alcoholic drinks cumulate the fewest scores with beer 1.7 on average only and vodka 1.9, 0.2 more because of the high temperature of the distillation process. Also the cold air dried discs in a cottage industrial setting accumulates a low average score of 2.1, with only a high score for its dry matter concentration. Modified starches reach the highest average with only low scores for oil use, costs of raw, keeping the original structure and the need for refrigeration of the produce. The averages of all other products do not diverge much from 3.0. Across the range of

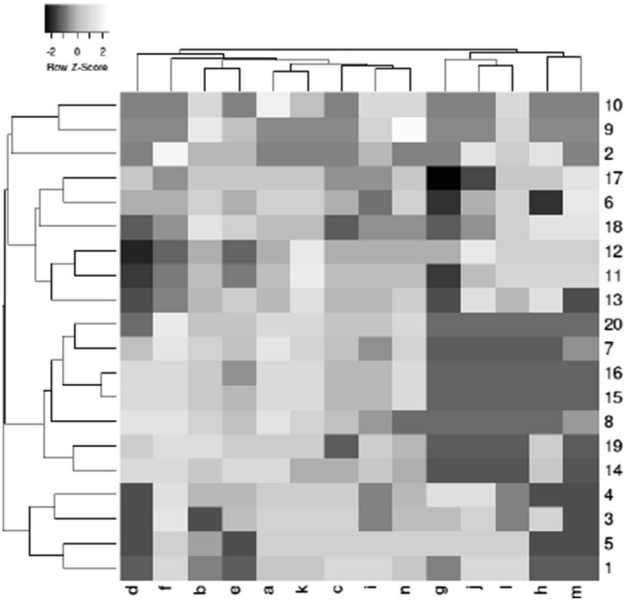
products use of them as an intermediate accumulates fewest scores 1.7 on average only. This because few products (the starches, flour and some dry products find their way to the food industry for sauces, soups, bread, pastry and frozen dishes. A cold chain, freezing and cooling, is only needed for the frozen and chilled products so this attribute also accumulates relatively few points.

The highest average, 3.8, applies to three attributes, energy need, dry matter concentration and advantage of large scale. Almost all processes, except drying and fermenting in the cottage industry require energy. The required energy is more or less equivalent to the resulting dry matter concentrations as evaporating water at any temperature is at the cost of energy. Most products except the drinks that have a lower concentration than the fresh tuber, canned, blanched and baked whole tubers that have concentrations similar to the raw material about 22%, the frozen products (French fries and formed have around 50% dry matter and the dry products (snacks and powders) less than 15%.

Clustering within the Processes Domain

The dendrogram in Table 10 shows four distinct clusters of products. The top three are the cottage industry products dried slices, beer and vodka. The cluster just below mainly contains water holding products and the one thereunder dry products, including snacks. The lowest cluster consists of the four products that did not experience a high temperature and therefore contain ungelatinized starch that needs to be reconstituted and heated before consumption. The closest twins are stackable chips and expanded snacks, but also par boiled French fries and

Table 10 Dendrogram of classes (1–20, Table 9) and their attributes (a-n, Table 9)



chilled cuts have much in common; the same applies to baked extrusion and baked cookies, native and modified starches and beer and vodka.

The clustering of the attributes is less distinct but a few obvious twins appear. Few specifications of raw are associated with its low price, the more energy is needed to make a product the greater the advantage of larger scale processing. Products sold in larger packages have more applications: snacks are sold in 50 − 200 g bags but flour and chilled tuber pieces in 500 – 2000 g packages. A twin at some distance is the need for a cold chain for chilled tubers, frozen baked tubers, par fried and par boiled French fries and the still recognizable tuber structure. Chips and canned tubers also retain much of the tuber structure but are stored at ambient temperatures so are at a large distance from the cold products.

The Domain of Factory Operations

Formulation of the Operations Domain

The domain is delimited by tubers delivered by lorry and tipped into the water at one end and entering the (cold) store of the factory as packed finished product ready to be delivered to the client at the other end of the domain. Except destoning and washing, not all finished products undergo all possible operations and processes tubers or parts thereof could be subjected to. Manufacturing native starch involves relatively few different operations at ambient temperatures whereas making frozen French fries requires many steps at ambient, blanching, deep-frying and deep-freezing temperatures. The main means of moving tubers and tuber parts from one operation to the other is by conveyor belts, but also Archimedes screws, spiral drums and pipes are vehicles employed. Often streams of material are separated by sieving, centrifuging, gravity or (optical) sorting where material not becoming the main finished product undergoes processes aimed at retaining as much value as possible. Slivers not fit for French fries or chips are blanched and drum dried into flakes for instance.

Condensation of the Operations Domain

The operations described here are summarized in Table 11. Removal of unsuitable particles, stones, clay caps, clods (Potato Business, 2021a), stem parts, tubers with too low dry matter is through water treatments (Kiremko, 2021a, b) and too small or too large tubers are graded. Unsuitable half products, peeled and fried fries and chips are sorted by eye or camera devices (Hassankhani and Navid 2012) and removed mechanically or by hand. Some products are sorted for various uses such as lengths of cuts and slivers for flakes manufacturing (Novus 2021).

For products that need peeling, this is done by knife, steam or abrasion but some products have peeled and skin-on versions (wedges, French fries, chips). In peeling a balance is sought between desired depth to remove all skin including that of the eyes and avoidance of losses (Pelletier et al. 1964). Starch processing has a sequence of particular processes including grating, sieving of the pulp, washing and refining of the starch, concentrating and flash drying to yield native starch ready for modification (Ratnayake and Jackson 2003). Disruption of the cell structure before cutting reduces resistance for

Table 11 Description of all operations; depending on finished product, tubers are subjected to a varying number of operations at different temperatures: operations at ambient temperatures; *operations at elevated temperatures*

Operation		Description
Destoning		Delivery of tubers in a washing basin, stones and clods sink to the bottom from where they are removed while tubers move vertically. In cyclone destoners water is pumped upward in vertical screw destoners to siphon water that takes tubers with it and leaves heavier material behind
Soaking and pre-washing		Removal of adhering soil and clay caps by rinsing the tubers in water moved by a spiral drum or an Archimedes screw
Brine separating		Destoned washed tubers contain light elements such as plant parts and low dry matter tubers. Passing a brine bath of 6% NaCl which is equivalent to a specific gravity (SG) of 1.06 removes the floaters (which have an SG below 1.06 and contain less than 16% dry matter)
Grading		Tubers pass a grid for proper sizing. For chipping 30 – 50 mm and for French fries cuts 45–90 mm size grades are desired
Peeling	Steam	*Perforated container with tubers subjected to steam of 200 °C at 18 bar for 8 s, upon withdrawing pressure, the skin pops off*
	Brushing	Removal of the remaining steam peels from the tubers with rotating brushes
	Abrasive	Tubers with running water placed in carborundum lined rotating drum or a drum with flint crystals loosen their skin which is washed away
	Cutting	Skin removal with a knife by hand (cottage industry)
	Trimming (cottage)	Removal with a knife by hand of undesired surface spots after mechanical peeling (cottage industry)
	Aggressive	Obsolete polluting techniques employed lye, brine, oil, flames
After-washing		Steam peeled and subsequently brushed tubers are washed to remove all remnants
Sorting		Optical technique to remove blemished peeled potatoes (with defects)
Pre-heating		*Disrupting cells of intact tubers for easier cutting and less shear: exposure to warm 55 °C water for 40 min. Pulse electric field exposure is applied for the same purpose*
Grating		Grating tubers into fine particles for starch extraction in (starch factories, ambient temperatures operation)
Washing starch		Washing the starch granules out of the cells in starch factories
Sieving pulp		Separating pulp from starch and juice wit extraction sieves in starch factories
Concentrating starch		With hydro-cyclones starch is concentrated in crude starch milk
Refining starch		Washing of the crude starch milk to remove juice
Shredding		Cutting elongated shreds (julienne) used in e.g. hash browns
Cutting	Halving, quartering	Oversized tubers are cut in halves or quarters to arrive at dimensions suitable for handling by the equipment and for specific end products
	Knife block	Water and tubers are piped at 40+ km/hour through a knife block producing French fries cuts and wedges of various sizes as directed by the maze of the knives
	Water jet	A water jet cuts tubers in slices
	Mechanical	Varying knife shape results in three dimensional shapes: dices, slices, ribbed, crinkled, waved, waffle shaped
	Slicer	Tubers are spinning in water with a stationary knife to produce slices of varying thickness, 1.5 mm thin for chips, 5 mm thick for chilled products

Table 11 (continued)

Operation		Description
Sorting	General	Removal of off-type tuber (parts) by eye or with camera aided equipment. Off-types are removed manually in small operations or mechanically (shoved, pricked, blown) in large ones
	Peeled	Removal of damaged or discoloured (black, green) tubers
	Products	(Half) finished products with defects, sugar ends for instance, are removed
	Sliver	Sliver remover takes away slivers and nubbins unfit for blanching and frying
	Length	A tuber produces French fries of different lengths, they are sorted in length classes
Drying	Ambient	Cottage industry in tropical countries: drying slices of raw tuber by exposure to sun and wind. Upon reconstitution with water the slices still need to be cooked
	Belt	*Blanched tuber parts are dried by hot air (flow of 70 °C) over a belt before par-frying the parts in oil*
	Hot air	*Super-heated steam (well above 100 °C) on raw potato slices, cooks and dries them*
	Flash	*Spread julienned tuber parts subjected to a stream of hot air cooks and dries them and avoid conglomeration*
	Drum	*Potato mash applied to a drum with a screw conveyer dried with steam is scraped off yielding flakes, flour when ground*
	Retro-gradation	First boiling or blanching followed by cooling slowly at 10 °C retrogrades gelatinized starch that takes up water leading to stronger fritters in hash browns
	Freeze	Chuño is made by spreading tubers at over 4000 m above sea level where they freeze at night and become hot during the day thereby desiccating
	Vacuum, Microwave	Freeze drying under vacuum and/or with microwave application speeds up the sublimation process
	Dewatering	In a starch plant, the starch suspension is dewatered, first by vacuum filtering followed by spreading the result in hot air of 160 °C for 2 s, just short enough to avoid gelatinization
Grinding		Ground flakes become flour
Blanching	*General*	*Heating tuber (parts) for a limited period (2 min) at a limited temperature (90 °C) and subsequently cooled to stop enzyme activity or for 5 min at 75° to cook (gelatinate). The process also removes excess reducing sugars and starch after cutting and the intermediate product is chilled and shelved and or immediately finished in next stages: frying baking, grinding and drum drying, cooking*
	Belt	*Conveyor belt with chips slices sprinkled with hot water*
	Steam	*Steam injected in screw driven tubers, readying them for mashing*
	Screw	*Hot water filled screw packed with French fries*
Dipping	SAPP	After blanching the product is dipped in a 1.5% SAPP (disodium acid pyrophosphate) solution to prevent after cooking darkening (ACD)
	Dextrose	The SAPP solution can be provided with a 1% dextrose (a reducing sugar, oleoresin of turmeric) to give fries a golden colour at frying
	Batter coating	Batter is a watery slurry of starches of potato, cassava, corn, rice and dextrins. When fried for the second time in the kitchen the coating enhances crispiness and flavour
Shredding		Cutting cooked tubers into thin several cm long strips of 2 mm^2
Chopping		Cutting cooked tubers before freezing arbitrarily into parts less than 20 mm
Dicing		Cutting cooked tubers before freezing into 1 cm cubes
Ricing		Pressing cooked tubers before forming through a ricer (sheet with small holes)

Table 11 (continued)

Operation		Description
Forming		Shaping potato dough, mash, shreds and riced blanched tuber into forms (croquettes, balls) before coating and frying
Par-frying		*Frying tuber parts at near cooking temperatures for less time than required for completing cooking (deep frying). The latter takes place when preparing the meal ingredient in the kitchen by adding frozen or chilled to heated oil*
Frying	*French fries*	*Mostly continuous over belt with steam cover over oil to prevent oxidation*
	Battered fries	*Battered fries first pass a hot oil bath to settle the batter than a second cooler oil bath to cook the product to the desired degree*
	Specialties	*Formed products are delicate and cannot be tossed like French fries so require special care to assure an even colour when led through the hot oil*
	Chips	*The chips are paddled when moving through the frying oil to avoid clumping and assure contact of the whole surface with the hot oil*
	Pellets	*Pellets expand manifold within some 10 s so need to be kept in the oil by a submerged conveyer belt*
	Kettle	*Frying unwashed, uncooked and thicker chips than in the continuous process, in batches in an oil bath (kettle)*
Oil removal		After (par) frying excess oil is removed by vibrating the belt on which they leave the oil bath
Cooling		After frying or blanching before freezing or chilling the product is cooled in a tunnel with an outside air stream
Freezing		Upon cooling with ambient air the chilled or par-fried product is frozen to -18 °C. To avoid clumping together of individual parts, they are 'individually quick frozen' (IQF) by cold air blown under the conveyor where they are
Chilling		Upon cooling with ambient air the chilled or par fried product is chilled to 4 °C
Extrusion (pelleting)		*Slightly moisturized flour is pressed through a mold and the string cut at regular intervals. The process yields pellets of exactly the same shape and size, ready to be fried and expand*
Expansion		*Exposing pellets to temperatures well above boiling, so deep frying or air frying expands them as the inside water forms steam which takes more space*
Flavouring		Adding flavour, seasoning, to chips and expanded products through a dispenser and tossing the product gently in a drum
Packaging		Wrapping products, dry ones in paper and carton packs, moisture containing ones chilled or frozen in plastic enrobed bags, boxes and trays
Pasteurizing/sterilization		*Heating the vacuum packed product to (near) boiling temperatures so it can be stored at 4 °C for a few months. When steam heated at above 100 °C, the shelf life is longer still*
Controlled atmosphere		Loosely stacked products where ambient air is replaced with air devoid of oxygen (nitrogen usually)
Anti-oxidant		Par fried or blanched products not frozen but chilled are supplied with an anti-oxidant to prolong their shelf life. Ascorbic acid is an example

cutting with water knives which saves energy and reduces losses through shear and breaking. Pre-heating in hot water is one method (Agblor and Scanlon 2000), subjecting tubers to a pulse electric field is another method widely applied in the processing

industry (Fauster et al. 2018; Fauster et al. 2020). Reducing tubers to smaller parts is through subjecting them to rasps, grates, water jets, knives in a block or placed in the wall of a drum (slicer): shredding, chopping, dicing, ricing (Potato Business 2021b). These operations result in pulp, halves, quarters, chips, slices and shreds. Drying is done on a range of tuber parts (whole, slices, cubes, mash) in a range of temperatures (freezing, ambient, hot, superheated) in a matter of days (chuño, sun and wind dried slices), minutes (drum drying of flakes and removing blanching water from slices and cuts) or seconds (flash drying of starch; Wang et al. 2010; Boutelba et al. 2018).

Heating of tubers occurs without water in the oven (baking), with water to near boiling temperature for a near fully cooking duration (blanching), in boiling water or steam (cooking) or in hot oil (frying). All these processes suffice to gelatinize the starch and render it digestible for humans (Van Loon 2005).

Depending on the specification of the finished product, a range of additives applied in different operations is available. 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 2005) 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 McDonalds 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. Snacks, chips and expanded snacks have a wide range of flavours beside the original sweet bell pepper (paprika) and salt & vinegar added.

Temperature, other than ambient related processes to make the finished products, in increasing order are freezing in freeze drying (-50 to -80 °C), cool air in retrograding (10 °C), hot water in blanching (75 °C), boiling water in cooking (100 °C), superheated steam (Sotome and Takenaka 2009) in cooking (130 °C), hot oil for par-frying (155 °C), hot oil for deep frying (175 °C) and hot air in oven baking (190 °C). Temperature related interventions regarding the finished product are aimed at storage prolongation (De Kock et al. 1994) in order of increasing temperature: freezing (-18 °C), chilling (3 °C), pasteurizing (90 °C) and sterilizing (125 °C, steam temperature).

Finished consumer products need packing that suits their protection from the environment, stackability and longevity. Powder (flour, granules) and flakes are packed in paper bags and cartons in ambient air, without cooling but protected from moisture. Formed frozen products are loosely packed in plastic (polyethene) bags without risk of deforming (Emmerson 2021). When displayed chilled, so at risk of compacting, they are placed in stackable aluminum or plastic trays (casseroles). Blanched or par-fried and chilled French fries and slices are not at risk of deformation and are either loosely stacked in controlled atmosphere or vacuum packed and pasteurized or sterilized.

The various groups of manufactured dried intact tuber pieces, dehydrated powders and pellets, fried, blanched and baked, totaling 22 products and the 66 processes yield 1452 grid cells in Table 12. Of all processes, 24 require water such as washing, peeling, blanching and dipping, the other 42 processes are 'dry' treatments. Operations where tubers, cuts or dough are heated number 18 and include steam peeling, pre-heating, par-

boiling and frying, drum drying and expansion of pellets by frying or baking. The other ones take place at ambient temperature or below such as chilling, freezing and freeze-drying. The physical operations such as heating, cooling and drying number 26, the other 40 concern mechanical operations such as grading, cutting and flavouring. Some generic operations, conveying, monitoring, weighing to mention a few are not included in the list as they apply to all products. Packaging does not apply to all products, native starch for instance, is not packed usually, but transported in bulk to its users, manufacturers in the food and non-food industry.

Drying tubers or pieces without grinding involves the fewest number of operations, six on average followed by dehydration whereby the original tuber structure is lost with about nine operations. Heating through baking and blanching leads to more opportunities to create intricate products with about thirteen operations. The greatest opportunities to create complex products are linked to frying with on average over twenty-two operations.

The fewest processes tubers go through is making chuño, washing and freeze drying although a third one, not listed in Table 12 is part of making chuño, namely crushing the tubers by foot to remove the skin and squeeze out the juice. Modern freeze drying requires seven steps including washing, peeling and drawing a vacuum. The highest number of processes, thirty one, is needed to make mash based fried and frozen products such as croquettes. To make battered frozen French fries, tubers undergo thirty processes. As is shown in Table 12, the more operations products are subjected to the higher the added value with the exception of chips with 21 operations which derives its high value from the degree of dehydration (fully at the cost of much energy), the costly ingredient (oil) and precious way of packing (loosely packed with ample controlled atmosphere in aluminum coated polyethene wrapping). The same holds for expanded snacks that have the same number of operations that apply to pellets (ten) but added frying, oil removal, flavouring and packing under controlled atmosphere.

Quantification of the Attributes of the Classes of Operations

Assigning scores between 1 and 5 according to the degree attributes applied to an operation creates the heatmap as shown in Table 13. The temperature at which the operations take place vary from -80 °C for freeze drying to 190 °C for baking. Some take place at intermediate products close to the raw material such as peeling, whereas packing is the last one products are subjected to. Some operations, among them grinding, completely destroy the structure of the tuber, whereas making jacket potato hardly alters it. Operations of varying duration, destoning is immediate upon immersion and air drying slices in the open takes a few days and operations to a varying degree influence the quality, flavouring very much so, and recovery, sorting does, cooling does not. Of the distinction between physical (green), drying is an example and mechanical (red), grading, only two colour codes were used. An operation contributes to a specialty such as retrograding upon blanching and shredding, both for making hash browns or not at all, oil removal for example. The use of energy is negligible in case of separating tubers in a brine bath or high in case of baking, similarly for the use of water which is zero in case of drying but relatively high in washing. The heatmap, colour scheme from dark green to dark red shown in Table 13, equivalent to values from 1 to 5 produces a dendrogram.

Table 12 Operations per product (Italics; skin-on products are not peeled, *x*)

		Category										
		Dried tuber					Dehydrate				Fried	
Process		Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/ granulate	Pellets	French fries	Chips
Destoning			x	x		x	x	x	x	x	x	x
Soaking and pre-washing		x	x	x	x	x	x	x	x	x	x	x
Brine separating										x	x	
Grading			x	x	x	x		x	x	x	x	x
Peeling	Steam			x				x	x	x	*x*	x
	Brushing			x								
	Abrasive											*x*
	Cutting				x							
	Trimming				x							
After washing				x				x	x	x	x	x
Sorting			x	x		x		x	x	x	x	x
Pre-heating											x	x
Grating, rasping							x					
Washing starch							x					
Sieving pulp							x					
Concentrating starch							x					
Refining starch							x					
Shredding												

Table 12 (continued)

		Category										
		Dried tuber					Dehydrate				Fried	
Process		Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/ granulate	Pellets	French fries	Chips
Cutting	Knife block										x	
	Halving										x	
	Water jet										x	
	Mechanical											x
	Slicer											x
Sorting	Peeled											
	Products										x	x
	Sliver										x	x
	Length										x	
Drying	Ambient										x	x
	Belt										x	x
	Hot air					x		x	x			
	Flash						x					
	Drum							x	x			
	Retrograde											
	Freeze	x	x	x								
	Vacuum		x									
	Dewatering						x					

Table 12 (continued)

		Category										
		Dried tuber					Dehydrate				Fried	
Process		Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/ granulate	Pellets	French fries	Chips
Grinding									x			
Blanching	Belt											x
	Steam											
	Screw										x	
	SAPP										x	
Dipping	Dextrose										x	
	Battering										x	
Shredding												
Chopping												
Dicing												
Ricing												
Forming										x	x	
Par-frying												
Frying	Battered										x	
	Specialties											
	Crisps/chips											x
	Pellets											
	Kettle										x	x

Table 12 (continued)

	Category										
	Dried tuber					Dehydrate				Fried	
Process	Chuño	Freeze dried uncooked	Freeze dried cooked	Cold air dried	Hot air dried	Starch (cold extraction)	Flakes	Flour/ granulate	Pellets	French fries	Chips
Oil removal										x	x
Cooling					x		x			x	x
Freezing										x	
Chilling										x	
Extrusion (pelleting)									x		
Expansion											
Flavouring											x
Packaging		x	x		x		x	x		x	x
Anti-oxidant										x	
Pasteurizing/sterilization									x		
Controlled atmosphere										x	x
Sum	2	7	9	4	7	9	10	10	10	30	22
Average	5.8					9.8				18.6	

Table 12 (continued)

		Category										
		Fried			Blanched				Baked			
Process		Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds	Canned	Jacket potato/ half shells	Casseroled	Gratinated	Rissoled
Destoning		x	x	x	x	x	x	x	x	x	x	x
Soaking and pre-washing		x	x	x	x	x	x	x	x	x	x	x
Brine separating		x										
Grading		x	x	x	x	x	x	x	x	x	x	x
Peeling	Steam	x	x	x	x	x	x	x		x	x	x
	Brushing											
	Abrasive											
	Cutting											
	Trimming											
After washing		x	x	x	x	x	x	x		x	x	x
Sorting		x	x	x	x	x	x	x	x	x	x	x
Pre-heating												
Grating, rasping												
Washing starch												
Sieving pulp												
Concentrating starch												
Refining starch												
Shredding				x			x					

Table 12 (continued)

		Category										
		Fried			Blanched				Baked			
Process		Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds	Canned	Jacket potato/ half shells	Casseroled	Gratinated	Rissoled
Cutting	Knife block											
	Halving											x
	Water jet											
	Mechanical					x				x	x	
	Slicer					x				x	x	
Sorting	Peeled				x	x	x	x				
	Products											
	Sliver											
	Length											
Drying	Ambient											
	Belt											
	Hot air											
	Flash											
	Drum											
	Retrograde			x								
	Freeze											
	Vacuum											
	Dewatering											
Grinding												

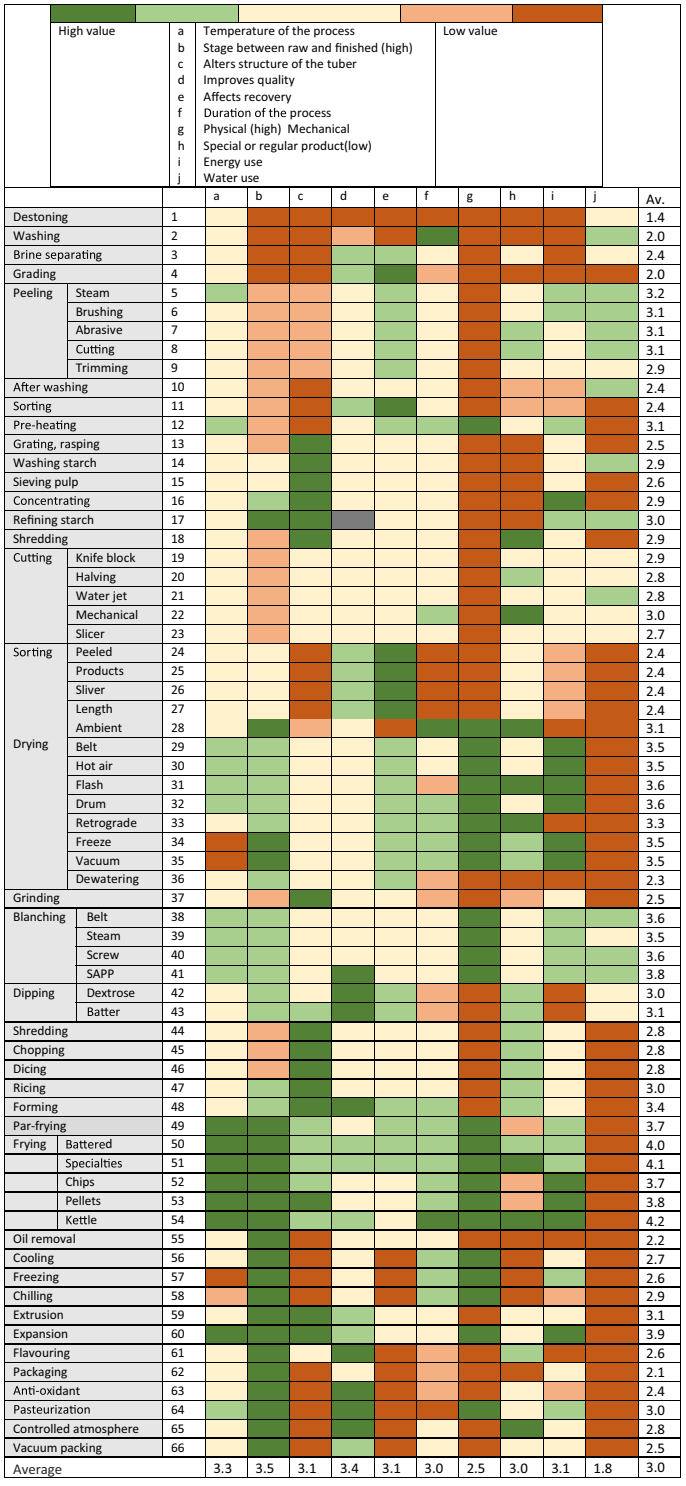
Table 12 (continued)

		Category									
		Fried			Blanched			Baked			
Process		Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds Canned	Jacket potato/ half shells	Casseroled	Gratinated	Rissoled
Blanching	Belt										
	Steam			x	x	x	x				
	Screw				x	x					
	SAPP										
Dipping	Dextrose										
	Battering										
Shredding				x			x				
Chopping							x				
Dicing							x				
Ricing			x								
Forming		x	x	x							
Par-frying			x								
Frying	Battered										
	Specialties		x	x							
	Crisps/chips										
	Pellets	x									
	Kettle										
Oil removal		x	x	x							
Cooling					x	x	x	x	x	x	x

Table 12 (continued)

	Category										
	Fried			Blanched				Baked			
Process	Extruded and expanded	Mashed and formed	Shredded and formed	Pre-cooked tuber/parts	Casseroled	IQF dices and shreds	Canned	Jacket potato/ half shells	Casseroled	Gratinated	Rissoled
Freezing		x	x					x	x	x	x
Chilling				x	x	x		x	x	x	
Extrusion (pelleting)											
Expansion	x										
Flavouring	x										
Packaging	x	x	x	x	x	x		x	x	x	x
Anti-oxidant				x							
Pasteurizing/sterilization				x	x	x	x	x	x	x	x
Controlled atmosphere						x		x	x	x	x
Sum	13	13	15	14	15	17	8	10	14	14	12
Average	18.6			13.5				12.5			

Table 13 Heatmap of 66 classes of operations and 10 attributes, degree to which they apply



			a	b	c	d	e	f	g	h	i	j	Av.
Destoning		1											1.4
Washing		2											2.0
Brine separating		3											2.4
Grading		4											2.0
Peeling	Steam	5											3.2
	Brushing	6											3.1
	Abrasive	7											3.1
	Cutting	8											3.1
	Trimming	9											2.9
After washing		10											2.4
Sorting		11											2.4
Pre-heating		12											3.1
Grating, rasping		13											2.5
Washing starch		14											2.9
Sieving pulp		15											2.6
Concentrating		16											2.9
Refining starch		17											3.0
Shredding		18											2.9
Cutting	Knife block	19											2.9
	Halving	20											2.8
	Water jet	21											2.8
	Mechanical	22											3.0
	Slicer	23											2.7
Sorting	Peeled	24											2.4
	Products	25											2.4
	Sliver	26											2.4
	Length	27											2.4
	Ambient	28											3.1
Drying	Belt	29											3.5
	Hot air	30											3.5
	Flash	31											3.6
	Drum	32											3.6
	Retrograde	33											3.3
	Freeze	34											3.5
	Vacuum	35											3.5
	Dewatering	36											2.3
Grinding		37											2.5
Blanching	Belt	38											3.6
	Steam	39											3.5
	Screw	40											3.6
	SAPP	41											3.8
Dipping	Dextrose	42											3.0
	Batter	43											3.1
Shredding		44											2.8
Chopping		45											2.8
Dicing		46											2.8
Ricing		47											3.0
Forming		48											3.4
Par-frying		49											3.7
Frying	Battered	50											4.0
	Specialties	51											4.1
	Chips	52											3.7
	Pellets	53											3.8
	Kettle	54											4.2
Oil removal		55											2.2
Cooling		56											2.7
Freezing		57											2.6
Chilling		58											2.9
Extrusion		59											3.1
Expansion		60											3.9
Flavouring		61											2.6
Packaging		62											2.1
Anti-oxidant		63											2.4
Pasteurization		64											3.0
Controlled atmosphere		65											2.8
Vacuum packing		66											2.5
Average			3.3	3.5	3.1	3.4	3.1	3.0	2.5	3.0	3.1	1.8	3.0

The highest average value of the attributes (4.1) is assigned to frying specialties such as patties, hash browns and croquettes followed by frying battered French fries (4.0). Relatively simple mechanical operations such as destoning, grading and packing cumulate few points (2 or less).

The highest average value of an attribute over all the operations is the stage between raw and finished (3.5); apparently most operations take place when the products are (almost) finished such as blanching and frying whereas basic operations at the beginning of entering the factory (washing, grading) are fewer in number. The temperature of the process also has a high average score because many processes involve a higher than ambient temperature. Of all the 66 operations tabled, only few have water involved, hence the low score (1.8) for water use.

The dendrogram of the factory operations and their attributes (not shown) clearly shows two main clusters. One contains all operations that involve the physical processes heating, cooling and drying, the other one all the mechanical operations. The cluster with physical processes has a few sub-clusters holding identical attributes; those are drum and hot air drying, belt and steam blanching and freeze and vacuum drying. Processes that resemble each other closely are frying regular and battered French fries, frying chips and pellets and the trio cooling, chilling and freezing and in the same subcluster at some distance, pasteurization. Pre-heating to soften tubers to facilitate cutting is closely affiliated with all blanching methods (belt, steam, screw, SAPP (sodium acid pyrophosphate)).

The 'mechanical' cluster also contains twins such as cutting in French fries size and halving, a triplets shredding, chopping, dicing and a quadruplets sorting of peeled tubers, sorting of slivers not fit as French fries but destined for flakes, sorting of different sizes of cuts and of finished products to be rejected or not. Related are removals of excess oil after frying and water after blanching in one sub-cluster but rather distinct, so are the two squeezing methods ricing and extrusion, the two conservation methods controlled atmosphere and the application of an anti-oxidant and dipping in a solution of dextrose or batter. Similarly, peeling and cutting or slicing of tubers are related and so are the operations where separation of tubers takes place by grading, sorting or brining which are in the same subcluster but at a large distance from the optical sorting of intermediate and finished products. The three mechanical peeling methods (abrasive, cutting and trimming) are near identical but at a large distance from the physical method of steam peeling.

The attributes consist of a single one 'physical or mechanical' and of three clusters. They reveal that the closer an operation is to the raw material, the more water is required (washing for instance), shorter operations (grading for example) have a greater impact on recovery than operations that take more time (in case of blanching). Impact on quality largely concerns specialties and higher temperatures evidently are accompanied by a greater use of energy and, at some distance in the same cluster by processes that alter the tuber structure. This results from frying and drying at high temperatures that is often preceded by mashing, shredding and chopping.

Discussion: Deliberations and Conclusions

The number of classes and attributes in this paper about the super-domain manufacturing covering products in supermarkets, processes products were subjected to and

factory operations where these processes take place is given in Table 14. This was done for in total 94 classes and 34 attributes and for the supermarket products twice in a theoretical triangulation with first the view of a user followed by the view of the producer. The number of times a score was given to an attribute is 1096.

The about 170 classes of potato products present in a supermarket are divided into subclasses by attributes on heating procedures (frying, boiling, baking), appearance (intact, cut, shredded, mashed, formed), dehydrated (snacks, flakes, flour) and storage temperature (ambient, chilled, frozen). Tables 2 and 3 illustrate this condensation process. In the heatmap they are further condensed to fresh, chilled, fries, formed, dishes, dry products, snacks and baked with attributes that in some cases permit a different appreciation of consumers than of processors. This theoretical transformation illustrated an appreciation of a product from the manufacturer's point of view and of the consumer where both agree regarding desired shelf temperature, fanciness and convenience but where consumers prefer a wide range of products concerning, weights, flavours, shapes at low prices, processors prefer the opposite with the results found on the shelves as a compromise. Fresh tubers have the lowest price but compared with products offer the least convenience to cooks. Products that provide more convenience involve more processes to manufacture them.

Clustering 'consumer products' groups has convenience as a central theme, 'processor products' are grouped according to costs associated with making them, the more factory operations the higher the costs. These happen to be the products that consumers are willing to buy as they offer most convenience. Further explorations in this domain are possible by refining the kind of user of products, cooks at home, in restaurants, caterings or institutions (theoretical) or to set the supply in a developing market with less products supplied and other demands applying.

Upon entering a processing plant and having gone through the basic operations including washing, tubers destined for a specific product undergo different processes. These operations are related to dehydration, conversion, blanching, frying and baking as demonstrated in Tables 5 and 6. Manufacturing of starch differs much from that of food stuffs. The former takes place at ambient temperatures upon rasping and involves filtering yielding fibre and, concentration yielding starch to be washed, refined and dried and, fruit water from which denaturalized protein emerges after heating or natural food grade protein upon chromatographical separation. The bulk of the native starch is modified to make it suitable for the non-food and food industry that makes use of the functionality thus created. These condensation efforts are revealed in Tables 7 and 8. Unless gelatinized the modified starches still need to be reconstituted and heated to render them suitable for human consumption. Except for drying and fermenting,

Table 14 Overview of the four domains figuring in this survey

Domain	Classes	Nr	Example of class	Attributes are about	Nr	Example of attribute
Supermarket	Products	8	Formed products	Properties	11	Price range
Processes	Products	20	Extruded, baked	Technology	13	Number of operations
Factory	Processes	66	Shredding	Techniques	10	Water use
Total		94			34	

heating is a process all finished food products have in common. The processes dehydration, conversion, blanching, frying and baking are subdivided by sub-processes that determine the finished products. Dehydration through extraction turns out starch, by freezing dried products, and flakes by drum drying. Examples of conversion are starch modification, forming of mash or dough into shapes to be fried with pellets as a specific group subject to expansion by heating by the snack industry, usually not the potato pellet manufacturer. Heatmapping the products emanating from the processes were supplied technical (temperatures, scale), not social (convenience, preferences) attributes as the latter received attention in the previous survey (Haverkort et al. 2022). The average score of attributes is high for products that undergo more processes such as dehydration + modification and low for home made and cottage industry fermented potato juice. Clustering distinguishes the gelatinized starch containing from the ones that still need reconstitution and heating. The products heated already, are grouped according to increasing temperatures (blanched, fried, baked) or, another discriminator based on reconstituted powder (starch or flakes) and products with recognizable potato or parts. Extending the heatmapping and clustering by adding social attributes is doable in a reiteration if so desired. These are feasibility in cottage industry, relative importance in developing markets, convenience, number of operations in kitchens needed upon purchase of the product, to name a few.

Tubers are subjected to many operations to expose them to the processes they have to go through: dehydration, transformation, and the several means of heating, drying and cooling. Condensation of the classes of operations and allocating them to products that undergo them (Tables 11 and 12) reveal 66 classes of operations of which the classes of fried products on average undergo 22, against 6 for the classes of dehydrated products. In the heatmap and its dendrogram the operations and their 10 attributes a dichotomy is recognized. One cluster comprises the physical processes and its three sub-clusters on elevating the temperature, lowering it and on dehydration, and one on mechanical operations with sub-clusters on size reduction (grinding, cutting et cetera) and separation (grading, sorting, brine separation). The former ones are associated with high energy use, as the pieces are subjected to par-boiling, drum drying, to frying and the latter ones, aimed at rejection have the greatest impact on recovery of finished products. The approach shown here is limited to a few attributes only and could be extended by the cost of an operation, the cost of machinery, the intricacy, the need to monitor closely, the feasibility in a cottage setting for instance. It is also of interest how easily, or not, the processes can be altered such that they make more efficient use of resources, or can be automated or replaced.

Declarations

Conflicts of interests/Competing interests P.C. Struik is Editor-in-Chief of Potato Research.

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