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WYDZIAŁ NAUK O ŻYWNOŚCI I BIOTECHNOLOGII

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ZASTOSOWANIE BIAŁEK MLEKA, WYBRANYCH BŁONNIKÓW I TŁUSZCZÓW DO OTRZYMYWANIA INNOWACYJNYCH SOSÓW SEROWYCH

Rozprawa doktorska wykonana w Zakładzie Technologii Mleczarstwa i Żywności Funkcjonalnej Katedry Technologii Żywności Pochodzenia Zwierzęcego

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Spis treści

1. Streszczenie 4
2. Lista publikacji stanowiących przedmiot rozprawy doktorskiej 8
3. Wprowadzenie teoretyczne na podstawie publikacji: 9
Szafrańska J. O., Sołowiej B. G. "Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects" (*publikacja I*) 9
3.1. Otrzymywanie sosu serowego 9
3.2. Stabilność produktu i termin przydatności do spożycia 14
3.3. Ocena sensoryczna sosów serowych 16
4. Hipoteza badawcza i cel pracy 17
5. Układ doświadczeń 18
5.1. Etapy weryfikacji założeń badawczych 18
5.2. Formuła badanego sosu serowego 20
6. Omówienie wyników i dyskusja 21
6.1. Przedstawienie dotychczasowego stanu wiedzy na temat produkcji sosów serowych 21
6.2. Badania dotyczące zastosowania koncentratu białek serwatkowych (WPC80) jako funkcjonalnego dodatku do sosów serowych (publikacja II) 22
6.3. Zastosowanie różnych źródeł półproduktów do otrzymywania sosów serowych 27
6.3.1. Wykorzystanie olejów (rzepakowego i kokosowego) oraz bezwodnego tłuszczu mlecznego jako elementów bazy do otrzymywania sosów serowych 27
6.3.2. Wykorzystanie błonników (cytrusowego, akacjowego, ziemniaczanego, bambusowego) jako potencjalnych dodatków prozdrowotnych i teksturotwórczych (III i IV publikacja) 27
6.3.3. Ocena organoleptyczna 41
7. Stwierdzenia i Wnioski 44
8. Publikacje wchodzące w skład rozprawy doktorskiej 52
9. Oświadczenie współautorów publikacji stanowiących przedmiot rozprawy doktorskiej .... **Error! Bookmark not defined.**
10. Zestawienie dorobku naukowego .... **Error! Bookmark not defined.**

1. Streszczenie

Zmieniający się styl życia przeciętnego konsumenta, a także nabywanie nowych nawyków żywieniowych związane np. z występującymi wszechobecnie alergiami pokarmowymi, spowodowały zapotrzebowanie rynku na innowacyjne produkty spożywcze. Coraz chętniej konsumenci sięgają po żywność o prostym składzie i zawierającą jak najwięcej komponentów prozdrowotnych. Dodatkowo wzrost świadomości dotyczącej m.in. zawartości w diecie poszczególnych składników odżywczych powoduje, że tworzenie nowych formuł i koncepcji produktów spożywczych, stanowi ważny element opracowywania tego typu żywności. Dlatego też prowadzenie różnorodnych badań jest niezbędne do opracowania gotowego produktu, który spełni wszystkie wymagania, zarówno producentów, jak i konsumentów.

Sos serowy znajduje szerokie zastosowanie jako dodatek do warzyw, różnego rodzaju makaronów czy mięs oraz jako dip do przekąsek. Jest łatwo dostępny w supermarketach i małych sklepach w różnych formach, na przykład jako proszek, który należy zalać gorącą wodą lub jako produkt gotowy do spożycia. Przewiduje się, że rynek sosów serowych będzie zwiększał się w prognozowanym okresie od 2017 do 2022 roku (Orbis Research, 2017).

W porównaniu z produktami komercyjnymi opracowana receptura wyróżnia się składem. Nie zawiera substancji dodatkowych tj. wzmacniaczy smaku (glutaminianu sodu, guanylanu sodu), skrobi modyfikowanych czy substancji zagęszczających w myśl Rozporządzenia 1129/2011 (Rozporządzenie Komisji Europejskiej nr 1129/2011, 2011). Dodatek koncentratu białek serwatkowych (WPC80) oraz błonników dietetycznych (nigdy wcześniej nie wykorzystywanych w tego typu produktach) wpływa na prozdrowotny charakter opracowanej receptury, jak również na cechy funkcjonalne oraz organoleptyczne.

Koncentrat białek serwatkowych o zawartości białka 80% (WPC80 ang. whey protein concentrate) jest składnikiem produktów bardzo chętnie wybieranych przez sportowców i osoby dbające o swoją dietę. Białka serwatkowe stanowią ważne źródło niezbędnych dla ludzkiego organizmu aminokwasów zawierających siarkę (metionina, cysteina), które mają działanie przeciwutleniające. Z naukowego punktu widzenia najcenniejsze w serwatce są jednak inne frakcje biologicznych związków - laktoferyna, beta-laktoglobulina, alfa-laktoalbumina, czy immunoglobuliny. Białka serwatkowe odgrywają istotną rolę w kontrolowaniu masy ciała, utrzymaniu sprawności fizycznej i zapobieganiu atrofii mięśni (Lammert i in., 2014). Z kolei kazeina kwasowa zawiera przeciętnie ok. 85% białka; 1,3% tłuszczu; 0,1% laktozy oraz 1,8% popiołu. Charakteryzuje się długim okresem trawienia, dzięki czemu po jej spożyciu do organizmu dostarczane są przez dłuższy czas odpowiednie dawki aminokwasów. Jej właściwości antykataboliczne powodują zahamowanie rozpadu masy mięśniowej (Belyaeva i in., 2021; Southward, 2018; Marshall i in., 2020).

Do stworzenia opisywanego produktu został wykorzystany bezwodny tłuszcz mleczny oraz różne rodzaje olejów (kokosowy i rzepakowy). Bezwodny tłuszcz mleczny powoduje zmniejszenie stężenia LDL oraz cholesterolu całkowitego w wątrobie i estrów cholesterolu (Herrera-Meza i in., 2013). Dodatkowo jest on źródłem antyoksydantów tj. skoniugowanego kwasu linolowego (CLA), witaminy E i A oraz koenzymu Q_{10} (Cichosz & Czeczot, 2012). Z drugiej strony badania potwierdzają, że olej kokosowy jest produktem dającym wiele pozytywnych skutków zdrowotnych, np. powoduje zmniejszenie całkowitego poziomu trójglicerydów, wpływa pozytywnie na stosunek cholesterolu LDL do HDL w organizmie. Jest bogaty w średniołańcuchowe kwasy tłuszczowe, które mają wpływ na przyspieszenie tempa przemian energetycznych (Gopala i in., 2009). Wykorzystany w badaniach olej rzepakowy charakteryzuje się niską zawartością nasyconych kwasów tłuszczowych i wysoką zawartością jednonienasyconych i wielonienasyconych kwasów tłuszczowych, tj. kwasów tłuszczowych omega-9, omega-6 i omega-3. Spożywanie tego oleju może mieć korzystny wpływ na profil lipidowy krwi, biomarkery hemostazy i zapalenia, czy metabolizm energetyczny (Lin i in., 2013).

Według niezależnych firm badawczych, zajmujących się śledzeniem nowych kierunków rozwoju związanych z produkcją żywności pod kątem obecnych i przyszłych trendów, zainteresowanie konsumentów błonnikami dietetycznymi zwiększa się każdego roku. Na podstawie badań i obserwacji prowadzonych od prawie 40 lat spożywanie co najmniej 25–29 g lub więcej błonnika dziennie powoduje zdecydowaną poprawę zdrowia (Komisja Europejska, 2016). Dodatkowo dzięki swojej budowie chemicznej może być dodawany do produktów mlecznych. Ten rodzaj innowacji wpływa na zwiększenie dostępności żywności bogatej w błonnik i w ten sposób poprawę zdrowia konsumentów.

W związku z powyższym tematem moich badań było zastosowanie białek mleka (kazeiny i białka serwatkowego), wybranych błonników dietetycznych (akacjowego, bambusowego, cytrusowego i ziemniaczanego) i różnych źródeł tłuszczu (olejów: rzepakowego i kokosowego oraz bezwodnego tłuszczu mlecznego) do otrzymywania innowacyjnych sosów serowych o właściwościach potencjalnie prozdrowotnych.

Summary

The changing lifestyle of the average consumer, as well as the acquisition of new eating habits related to, for example, ubiquitous food allergies, caused the market demand for innovative food products. Consumers are more and more willing to reach for food with a simple composition and containing as many health-promoting components as possible. In addition, an increase in awareness of the content of individual nutrients in the diet means that the creation of new formulas and concepts of food products is an important element in the development of this type of food. Therefore, conducting a variety of research is necessary to develop a finished product that will meet all the requirements of both producers and consumers.

The cheese sauce is widely used as an addition to vegetables, various types of pasta or meats, and as a dip. It is readily available in supermarkets and small shops in many forms, for example as a powder to be poured with hot water or as a ready-to-eat product. The cheese sauce market is expected to increase in the forecast period from 2017 to 2022 ((Orbis Research, 2017).

Compared to commercial products, the developed recipe is distinguished by its composition. It does not contain additional substances, i.e. flavor enhancers (monosodium glutamate, sodium guanylate), modified starches or thickeners in accordance with regulation 1129/2011 (Rozporządzenie Komisji Europejskiej nr 1129/2011, 2011). The addition of whey protein concentrate (WPC80) and dietary fibers (never before used in this type of products) affects the health-promoting nature of the developed recipe, as well as functional and sensory features.

Whey protein concentrate with a protein content of 80% (WPC80) is a component of products very eagerly chosen by athletes and people who care about their diet. Whey proteins are an important source of essential sulfur-containing amino acids (methionine, cysteine) that have an antioxidant effect. From the scientific point of view, the most valuable in whey are other fractions of biological compounds - lactoferrin, beta-lactoglobulin, alpha-lactalbumin or immunoglobulins. Whey proteins play an important role in weight control, maintaining fitness, and preventing muscle atrophy (Lammert et al., 2014). In turn, acid casein contains an average of about 85% protein; 1.3% fat; 0.1% lactose and 1.8% ash. It is characterized by a long period of digestion, thanks to which, after its consumption, appropriate doses of amino acids are supplied to the body for a long time. Thanks to its anti-catabolic properties, it

inhibits the breakdown of muscle mass (Belyaeva et al., 2021; Southward, 2018; Marshall et al., 2020).

Anhydrous milk fat and various types of oils (coconut and rapeseed) were used to create the described product. Anhydrous milk fat reduces the concentration of LDL and lowers total hepatic cholesterol, and cholesterol esters (Herrera-Meza et al., 2013). Additionally, it is a source of antioxidants, i.e. conjugated linoleic acid (CLA), vitamins E and A, and coenzyme Q10 (Cichosz & Czeczot, 2012). On the other hand, research confirms that coconut oil is a product with many beneficial health effects, e.g. it reduces the total level of triglycerides, and has a positive effect on the ratio of LDL to HDL cholesterol in the body. It is rich in medium-chain fatty acids, which accelerate the pace of energy transformation (Gopala et al., 2009). Rapeseed oil used in the research is characterized by a low content of saturated fatty acids and a high content of monounsaturated fatty acids and polyunsaturated fatty acids, i.e. omega-9, omega-6 and omega-3 fatty acids. Consuming this type of oil may have a positive effect on the blood lipid profile, biomarkers of hemostasis and inflammation, and energy metabolism (Lin et al., 2013). According to independent research companies, tracking new directions of food production related to development in terms of current and future trends, consumer interest in dietary fibers is increasing every year. Research and observations conducted for almost 40 years provides data which suggest that consuming at least 25-29 g or more of fiber on dial basis cause significant improvement in health (The European Commission, 2016). Additionally, thanks to their chemical structure, they can be added to dairy products. This type of innovation can increase the availability of high-fiber foods and thus affect the health of consumers.

In connection with the above, the topic of my research was the use of milk proteins (casein and whey protein), selected dietary fibers (acacia, bamboo, citrus and potato) and various sources of fat (rapeseed and coconut oils and anhydrous milk fat) to obtain innovative cheese sauces with potentially health-promoting properties.

2. Lista publikacji stanowiących przedmiot rozprawy doktorskiej

PUBLIKACJA I

Szafrańska J. O., Sołowiej B. G., 2019, Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects. *Journal of Food Process Engineering*, 43(4), 3, 1-14.

Punkty MEiN: **100** IF $_{(2019)}$: **1,703** Liczba cytowań wg Web of Science (0)/Scopus (0)

PUBLIKACJA II

Szafrańska J. O., Muszyński S., Sołowiej B. G., 2020, Effect of whey protein concentrate on physicochemical properties of acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat. *LWT - Food Science and Technology*, 127, 18, 1-7.

Punkty MEiN: **100** IF$_{(2019)}$: **4,006** Liczba cytowań wg Web of Science (2)/Scopus (1)

PUBLIKACJA III

Szafrańska J. O., Sołowiej B. G., 2020, Effect of different fibres on texture, rheological and sensory properties of acid casein processed cheese sauces. *International Journal of Food Science and Technology*, 55(5), 12, 1971–1979.

Punkty MEiN: **70** IF$_{(2019)}$: **2,773** Liczba cytowań wg Web of Science (2)/Scopus (2)

PUBLIKACJA IV

Szafrańska J. O., Muszyński S., Tomasevic I., Sołowiej B. G., 2021, The influence of dietary fibers on physicochemical properties of acid casein processed cheese sauces obtained with whey proteins and coconut oil or anhydrous milk fat. *Foods,* 10, 759.

Punkty MEiN: **70** IF$_{(2019)}$: **4,092** Liczba cytowań wg Web of Science (0)/Scopus (0)

Sumaryczna liczba pkt. według komunikatu MEiN obowiązującego w roku wydania pracy: **340**

Sumaryczny IF (zgodnie z rokiem opublikowania): **12,574**

Sumaryczna liczba cytowań wg Web of Science (4) oraz Scopus (3)

3. Wprowadzenie teoretyczne na podstawie publikacji: Szafrańska J. O., Sołowiej B. G. “Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects” (*publikacja I*)

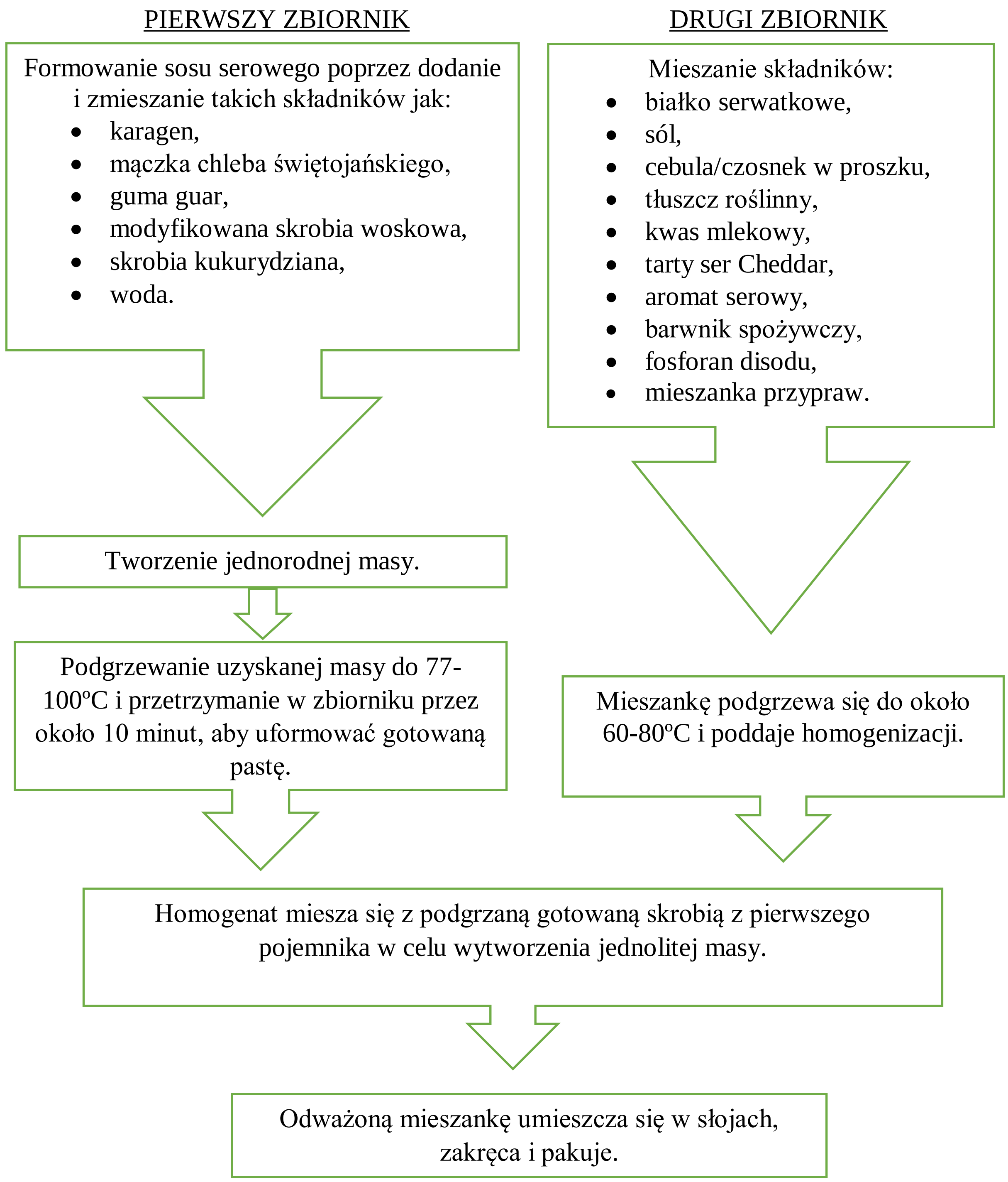
Sos definiuje się zwykle jako płynny lub półpłynny składnik potraw, dodawany głównie w celu wzmocnienia ich smaku. Sos serowy często podawany jest jako przystawka lub dodatek do głównego dania (Chandan et al., 2016). Może pełnić wiele funkcji, na przykład nadawać potrawom smak, poprawiać ich nawilżenie, konsystencję lub sprawiać, że niskokaloryczne dania stają się bardziej treściwe. Najczęściej wykorzystywanymi bazami sosów serowych są sery lub sery topione. Uznaje się je za rodzaj dodatku zagęszczającego (Salek i in., 2019). Sosy, ze względu na lekką konsystencję, przygotowywane są w taki sposób, aby podkreślić smak serwowanego dania. Można je podawać na ciepło lub zimno i jest to podstawowa różnica, która odróżnia je od dipów (Service International Food Information, 2009).

Sos serowy stanowi bardziej skomplikowany pod względem formuły artykuł spożywczy niż zakładają przeciętni konsumenci. Ponieważ nie ma własnej kategorii jako produkt, producenci podczas jego przygotowywania mogą stosować różnorodne bazy i dodatki. Jednak ważne jest, aby każdy składnik posiadał zdolność rozpuszczania się w wodzie. Zagwarantowanie tej cechy pozwoli na uzyskanie praktycznie każdego możliwego rodzaju sosu (Brandt, 2001).

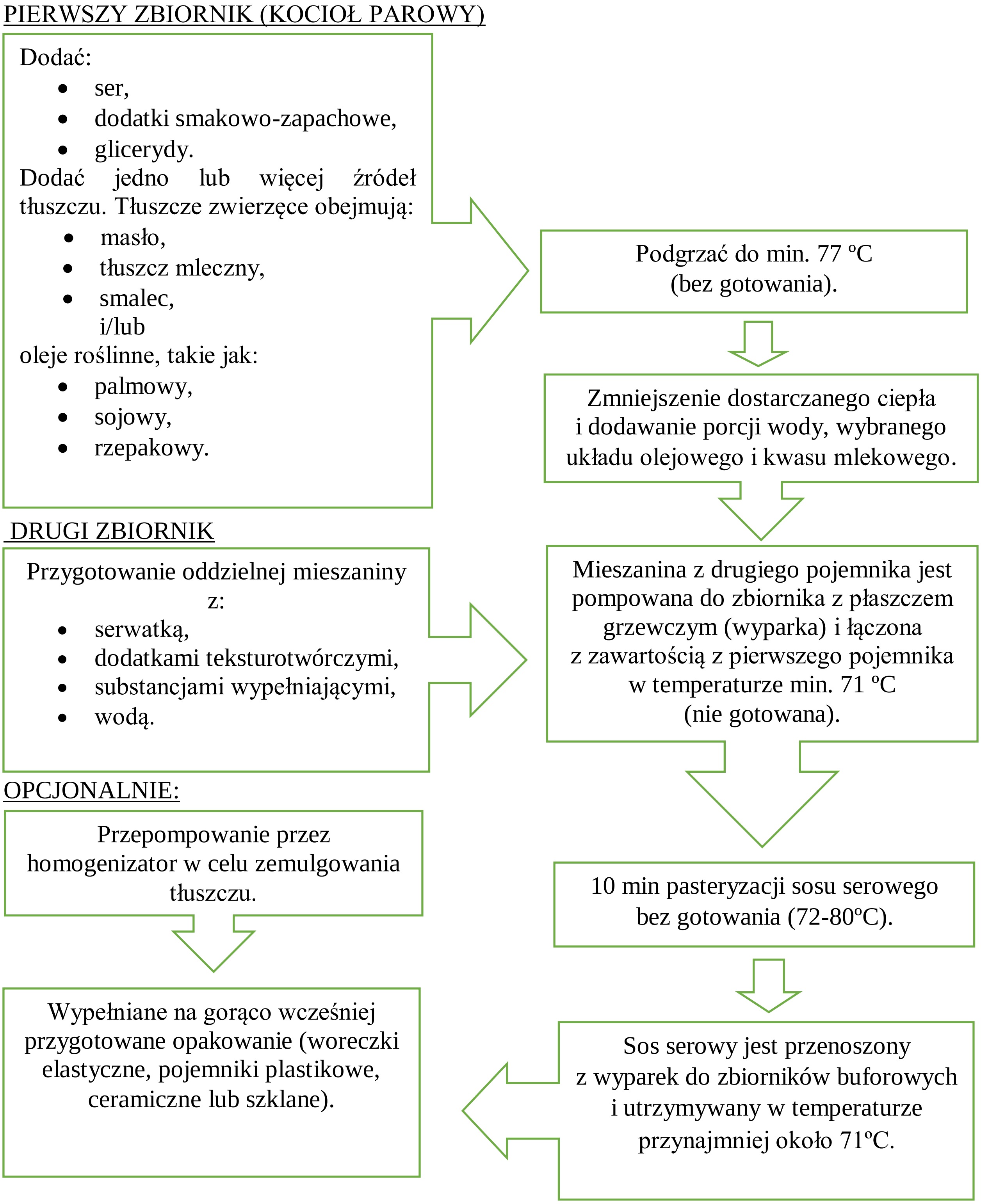
3.1. Otrzymywanie sosu serowego

Nie ma jednego konkretnego schematu opisującego proces produkcji sosu serowego. Ze względu na mnogość składników, z których można go wykonać, do tej pory zarejestrowano kilkanaście patentów, w których przedstawiono metody jego wytwarzania wraz z dokładnymi proporcjami półproduktów potrzebnych do uzyskania finalnego produktu. Jeden z pierwszych patentów opisujących produkcję sosu serowego został zarejestrowany w 1986 roku (Spanier, 1986) (Rysunek 1), a przykład późniejszych modyfikacji receptury stanowi patent z 2008 roku (Gamay i in., 2011) (Rysunek 2).

Aby stworzyć emulsję z wodą, co przedstawiono na rysunkach 1 i 2, autorzy zasugerowali użycie olejów. W pierwszej metodzie produkcji (Rysunek 1) proponuje się stosowanie tłuszczu roślinnego - oleju kokosowego, kukurydzianego lub sojowego, gdyż jak sugerują autorzy patentu, w przypadku tego typu aplikacji sprawdzają się lepiej niż oleje zwierzęce, które cechują się większą podatnością na jełczenie (Spanier, 1986). W przypadku drugiej metody (Rysunek 2) wykorzystano zrównoważone ilości zarówno tłuszczu zwierzęcego, jak i olejów roślinnych. Na rysunku 2 pokazano, że zmniejszenie wpływu olejów na teksturę jest możliwe po dodaniu odpowiednich wypełniaczy, takich jak stały syrop kukurydziany lub maltodekstryny.



Rysunek 1. Schemat blokowy produkcji sosu serowego na podstawie patentu z 1986 roku nr 4,568,555 (Spanier, 1986).



Rysunek 2. Schemat blokowy produkcji sosu serowego na podstawie patentu z 2011 nr 2011/0045145 (Gamay i in., 2011).

Metoda produkcji z 1986 roku opiera się na mieszance gum i skrobi, których odpowiednie połączenie jest bardzo ważne dla uzyskania dobrego smaku. Gumy wpływają na teksturę sosu serowego i dzięki ich wykorzystaniu można kontrolować lepkość produktu.

Podczas produkcji często stosuje się alginiany będące solami kwasu alginowego. Najczęściej stosowaną solą jest alginian sodu. Umożliwia on odpowiednie przyleganie sosów serowych do spożywanego produktu. Alginiany są stabilne przy niskim pH i zmniejszają prawdopodobieństwo tworzenia cienkiej, lepkiej (białkowo-tłuszczowej) błony na wierzchniej warstwie sosów (Trond i in., 2010). Typowa ilość stosowana podczas produkcji waha się od 0,3 do 1,0%. Jedną z ich funkcji jest zmniejszenie ilości wykorzystywanego sera naturalnego, przy jednoczesnym zwiększeniu wilgotności sosu serowego. Kolejnymi funkcjami jest stabilizacja emulsji, zmniejszenie utraty tłuszczu i poprawa trwałości produktu końcowego. Ponadto alginiany znane są ze swojego oddziaływania z niezwiązanymi jonami wapnia, co w konsekwencji powoduje zwiększenie lepkości produktu. W zależności od stosunku alginianu do jonów wapnia, roztwór może być zagęszczony lub zżelowany (Burrington, 2003; Trond i in., 2010). Z kolei skrobia, charakteryzująca się wieloma przydatnymi cechami w procesie wytwarzania sosu serowego, bierze udział w regulacji lepkości i wiązaniu wody, co wpływa na ostateczną teksturę sosu (Spanier, 1986). Jest stosowana w celu zmniejszenia kosztów produkcji, wydłużenia okresu przydatności do spożycia i uproszczenia deklaracji na etykiecie (Taggart & Mitchell, 2009). Skrobie zawierają amylopektynę, która ma różne funkcje i występuje w różnych ilościach. Zwykle skrobia typu wosku jest używana do produkcji sosów serowych ze względu na dużą ilość amylopektyny. Ma specyficzną strukturę, która może nadać produktowi gładką konsystencję. Innym rodzajem skrobi wykorzystywanych do produkcji sosów serowych są skrobie ryżowe o małych rozmiarach cząstek, co zapewnia gładką teksturę (Burrington, 2003). Do produkcji używa się również skrobi z tapioki, kukurydzy, pszenicy i ziemniaków (Sheldrake, 2003).

Innym składnikiem powszechnie wykorzystywanymi w produkcji sosów serowych jest ser naturalny. Wpływa nie tylko na smak sosu, ale także na jego masę oraz konsystencję. Nadaje odpowiednią teksturę finalnemu produktowi i poprawia przyczepność do potrawy, z którą jest podawany. Zazwyczaj zmniejszenie ilości opisanego dodatku w sosach pogarsza ich lepkość i konsystencję (Banes i in., 2014). W zależności od rodzaju, ale także wieku wykorzystanego sera można uzyskać całkiem inne produkty końcowe. Młodsze sery zapewnią łagodniejszy smak w porównaniu do starszych, które są bardziej aromatyczne. Ze względu na działanie bakterii i grzybów podczas dojrzewania serów, białka i tłuszcze dzielą się na prostsze związki, takie jak aminokwasy i wolne kwasy tłuszczowe. Jednocześnie zwiększa się ich rozpuszczalność, co wzmacnia smak sera. Ser dojrzewający od 2 do 5 miesięcy będzie łagodniejszy niż starszy, dojrzewający dłużej niż 5 miesięcy (Gamay i in., 2011). Czasami producenci mieszają starsze sery z młodszymi odmianami, aby uzyskać określony, pożądany efekt smakowy. Ponadto dojrzewający ser będzie miał zmniejszoną zdolność emulgowania. Stosowanie dojrzałego sera w produkcji skutkuje krótszą i bardziej kruchą teksturą sosu serowego. Sery, które wykorzystuje się najczęściej do produkcji sosów, to Cheddar, ser modyfikowany enzymatycznie (EMC), sery ziarniste, parmezan lub Provolone (Krumhar i in., 1998).

Jako zamiennik naturalnego sera bardzo często stosuje się ser w proszku. Zapewnia on najlepsze połączenie smaku i tekstury w produktach spożywczych, typu sosy i jest wytwarzany z serów, takich jak Camembert lub Cheddar (da Silva i in., 2018). Ilość sera w proszku używanego do produkcji wynosi zazwyczaj od 5 do 10%, w zależności od pożądanej intensywności smaku. Zawartość tego składnika zależy również od poziomów i rodzajów innych środków aromatyzujących (Fox i in., 2017).

Kolejnym składnikiem wykorzystywanym w produkcji sosów serowych jest modyfikowane białko serwatkowe (MWP - ang. modified whey protein). Jego funkcja jest podobna do tłuszczu, a jego zastosowanie pozwala na zmniejszenie ilości sera używanego do produkcji. Powoduje również poprawę tekstury. Nie należy jednak mylić MWP ze skrobiami i hydrokoloidami, które są prawdziwymi składnikami zwiększającymi lepkość i nie można ich całkowicie wyeliminować podczas produkcji sosu. Ich dodatek pozwala obniżyć koszt MWP w porównaniu do prawdziwego sera, co jest również zaletą (Banes i in., 2014).

Hydrokoloidy to substancje wielkocząsteczkowe, które mogą rozpuszczać się zarówno w zimnej, jak i w ciepłej wodzie, tworząc jednocześnie układy dyspersyjne i lepkie roztwory. Ich kluczową rolą jest kształtowanie struktury produktu i nadanie mu odpowiedniej stabilności (Dłużewska & Krygier, 2007). Poszczególne hydrokoloidy najczęściej używane do produkcji sosów serowych to alginiany, guma ksantanowa, karageny i guma guar (Hassan i in., 2015). Pomagają wiązać wodę, regulować lepkość sosów i przyczyniają się do uzyskania gotowej tekstury (Burrington, 2003). Warunki ogrzewania, pH i dyspergowalność są ważnymi czynnikami oceny hydrokoloidów stosowanych w produkcji sosów serowych (Saha & Bhattacharya, 2010).

3.2. Stabilność produktu i termin przydatności do spożycia

Poprawa stabilności i trwałości gotowego produktu związana jest, nie tylko z dodatkiem hydrokoloidów i emulgatorów, ale także innych składników. W celu wydłużenia terminu przydatności do spożycia, producenci używają wielu różnych produktów, na przykład sera lub mleka w proszku. Jedną z głównych zalet proszku serowego jest jego większa trwałość związana z niską aktywnością wody. Taka stabilność pozwala na łatwe łączenie z innymi suchymi komponentami w przeciwieństwie do serów, które przed zastosowaniem w produkcji należy poddać odpowiedniej obróbce. Ponadto umożliwia długotrwałe przechowywanie bez zmian jakości produktu (Fox i in., 2004).

Aktywność wody (a_w) stanowi jedną z głównych cech ograniczających trwałość produktu podczas przechowywania. Wysoka zawartość wody stwarza korzystniejsze warunki dla rozwoju pleśni i grzybów, a także wpływa na namnażanie się bakterii. W zapakowanych sosach serowych, które zawierają w środku opakowania wolną przestrzeń, można zaobserwować, że cząsteczki wody opuszczają żywność i rozprzestrzeniają się do otaczającej atmosfery (Yousef & Balasubramaniam, 2014). Aktywność wody jest związana z pH sosu serowego; zgodnie z wytycznymi Agencji Żywności i Leków, FDA (ang. Food and Drug Administration), produkt spożywczy o pH wyższym niż 4,6 jest trwały tylko wtedy, gdy jego aktywność wody wynosi 0,85 lub mniej. W sosach serowych pH wynosi zazwyczaj 5,8 (Gamay & Schumacher, 1999).

Ze względu na wysoki poziom tego współczynnika w sosach serowych, produkt końcowy jest narażony na zwiększony rozwój bakterii. Aby go zahamować, ważne jest, aby dodać odpowiednie związki, które będą zapobiegać wzrostowi patogenów w czasie i wydłużać okres przydatności do spożycia produktu końcowego. Dlatego też kwas sorbowy jest często dodawany jako inhibitor drożdży lub pleśni przez co wydłuża okres trwałości finalnego wyrobu (Gamay i in., 2011). Z kolei kwas mlekowy, dodawany jest zazwyczaj, aby uniknąć konsekwencji związanych z nadmierną ilością soli fosforanowych wykorzystywanych do produkcji sosu serowego (Spanier, 1986).

Wartość pH sosu serowego wpływa na teksturę, pożądany smak, a także na zrównoważony rozwój bakterii i patogenów. W XX wieku przeprowadzono wiele badań w celu określenia optymalnych warunków przygotowania produktów serowych, takich jak sosy serowe lub produkty do smarowania pieczywa, oraz produktów z zawartością sera powyżej 20% masy. Testy przeprowadzone przez Tanaka i in. (1986) wykazały, że optymalne pH sosów serowych wynosi $<5,7$ i parametr ten może być modyfikowany przez dodatek soli fosforanowych, chlorku sodu lub kwasu sorbowego (Tanaka i in., 1986). Dodatkowo pH sera wykorzystanego w produkcji wpływa na konfigurację białek. Specyficzne wartości pH odpowiadają ich punktom izoelektrycznym, co zmniejsza ich interakcje z innymi fazami. Kontrolowanie tego parametru można przeprowadzić poprzez dobór odpowiedniego sera oraz innych składników, które są używane do produkcji sosów serowych (Burrington, 2003). W produktach tego typu z zawartością różnych źródeł białka nie ma dużych różnic w określonych wartościach pH. Saad, EL-Mahdi, Awad i Hassan (2016) udowodnili, że wartości pH w badanych przez nich sosach serowych wahały się od 5,85 do 5,78. Różnice mogą wynikać ze struktury i pochodzenia badanych wyrobów. Dowiedli również, że po 3 miesiącach przechowywania w temperaturze pokojowej oraz 5°C, wartości pH sosów powoli zmniejszały się we wszystkich próbkach do końca okresu przechowywania. Nie było istotnych różnic w końcowym pH pomiędzy próbkami przechowywanymi w temperaturze pokojowej a tymi przechowywanych w temp. 5°C (odpowiednio 5,62 i 5,65) (Saad i in., 2016).

Dobór odpowiedniego fosforanu wpływa zarówno na topienie, jak i teksturę sosów serowych. Ponadto sole fosforanowe rozpuszczają białka pochodzące z sera i produktów mlecznych, które mogą działać jako emulgator. Ładunki dodatnie na białkach kazeiny oddziałują z anionowymi fosforanami, co może powodować rozwijanie białek, dzięki czemu zachowują się jak emulgatory (Pelofske, 2016). W 2019 roku badacze przetestowali różne rodzaje soli emulgujących (ES), które można wykorzystać do przygotowania sosów serowych: wodorofosforan disodu, disfosforan tetrasodowy, trifosforan pentasodowy, sól sodowa polifosforanu i cytrynian trójsodowy (Salek i in., 2019).

Jeden z patentów opisuje policykliczny peptyd o działaniu przeciwbakteryjnym - nizynę, jako substancję stosowaną do zapobiegania rozwojowi drobnoustrojów. Musi być dodawany w ilości do około 500 ppm całkowitej receptury sosu serowego, co jest maksymalną wartością zatwierdzoną przez FDA dla sosów. Według Gamay i in. (2011) należy stosować maksymalny poziom nizyny, ponieważ z czasem ulega ona degradacji (Gamay i in., 2011). W krajach, które nie zatwierdziły nizyny jako środka konserwującego, można stosować dekstrozę. Saad, El-Mahdi, Awad i Hassan (2015) podali, że dodanie konserwantów (nizyna; nizyna + sorbinian potasu; nizyna + natamycyna + sorbinian potasu; nizyna + natamycyna) do sosów serowych otrzymanych na bazie sera Ras skutkowało zahamowaniem wzrostu chorobotwórczej mikroflory (Saad i in., 2016).

3.3. Ocena sensoryczna sosów serowych

Wszystkie innowacyjne produkty i nowe receptury, w tym omówione sosy serowe, powstają w oparciu o wymagania rynku i gusta konsumentów. Dlatego też ocena gotowych produktów pod względem właściwości organoleptycznych i wizualnych jest bardzo ważna (Esmerino i in., 2017). Nawet niewielkie zmiany w składzie produktu mogą wpłynąć na smak lub wrażenia wizualne konsumentów. W celu lepszego zrozumienia ich potrzeb, testy sensoryczne zazwyczaj przeprowadza się w grupach mieszanych kobiet i mężczyzn w każdym wieku. Tego typu badania dają pełniejszy obraz jakości i oceny produktu końcowego (Oliveira i in., 2017; Torres i in., 2017).

Przy opisywaniu sosów serowych przez konsumentów należy zapytać o różne czynniki takie jak wygląd produktu, jego smak czy konsystencję. Skala zastosowana w badaniu powinna być obszerna i dobrze opisana. Dla przykładu, aby opisać charakterystykę sensoryczną sera topionego do smarowania, badacze często posługują się pięcioma grupami do opisania indywidualnych cech, takich jak wygląd (barwa i jasność), aromat i smak (skala związana z badanym produktem), konsystencja wizualna (konsystencja, smarowność, przyczepność, i jednorodność) (Torres i in., 2017).

Innym sposobem badania i oceny gustów konsumentów są techniki projekcyjne, importowane z innych obszarów do zastosowań w analizie sensorycznej, które zostały wykorzystane w badaniach marketingowych i konsumenckich opartych na subiektywnej opinii. W tej metodzie nie ma dobrych ani złych odpowiedzi (Soares i in., 2017). Składają się one z zestawu technik jakościowych, w których osoba może przedstawić swoją osobowość, postawę i opinie. Są to podejścia nieinwazyjne, a jedną z takich technik jest zadanie polegające na skojarzeniu słów. Jest to skuteczna metoda, w której respondenci proszeni są o podzielenie się swoimi pierwszymi wrażeniami związanymi z prezentowanym produktem - swoimi przemyśleniami i uczuciami (Esmerino i in., 2017). Podczas testowania sosów serowych można stosować obie metody. Każda z nich skupia się na badaniu rynku konsumenckiego i gustów konsumenckich. Jednak pierwsza opisana technika jest mniej uciążliwa dla ankietowanych i wymaga mniej energii oraz zasobów producentów. Pomaga też w szybszym pozyskiwaniu dużej ilości danych, a badanie można przeprowadzić na dużej liczbie osób z różnych grup wiekowych i społecznych, co silnie wpływa na wiedzę zdobytą przez badaczy.

4. Hipoteza badawcza i cel pracy

Na podstawie analizy danych literaturowych postawiono następującą hipotezę badawczą:
Opracowanie nowej formuły sosu serowego na bazie kazeiny kwasowej, koncentratu białek serwatkowych (WPC80 – ang. whey protein concentrate, o zawartości białka ok. 80%), różnych źródeł tłuszczu (oleju kokosowego, oleju rzepakowego, bezwodnego tłuszczu mlecznego) oraz różnego rodzaju błonników dietetycznych (akacjowego, bambusowego, cytrusowego, ziemniaczanego), które nigdy wcześniej nie były wykorzystywane w tego typu produkcie.

Celem głównym pracy było określenie wpływu poszczególnych składników formuły opisanego produktu m.in. na jego teksturę (twardość, przylegalność (adhezyjność), lepkość, właściwości lepkosprężyste (moduły: sprężystości i lepkość (G' i G''), tg kąta fazowego, granicę płynięcia), aktywność wody, gęstość i barwę.

W celu weryfikacji tak sformułowanych założeń badawczych wyznaczono następujące cele szczegółowe:

- Określenie możliwości i ilości potrzebnego koncentratu białek serwatkowych (WPC80) do produkcji sosu serowego.
- Ocena wpływu zawartości zastosowanego koncentratu białek serwatkowych (WPC80) na właściwości fizykochemiczne sosów serowych.
- Wykorzystanie różnych źródeł tłuszczu jako dodatku do bazy sosu.
- Wykorzystanie różnego rodzaju błonników dietetycznych jako dodatku do testowanego sosu serowego.
- Ocena wpływu poszczególnych składników oraz ich ilości na właściwości fizykochemiczne i organoleptyczne sosów serowych.

5. Układ doświadczeń

5.1. Etapy weryfikacji założeń badawczych

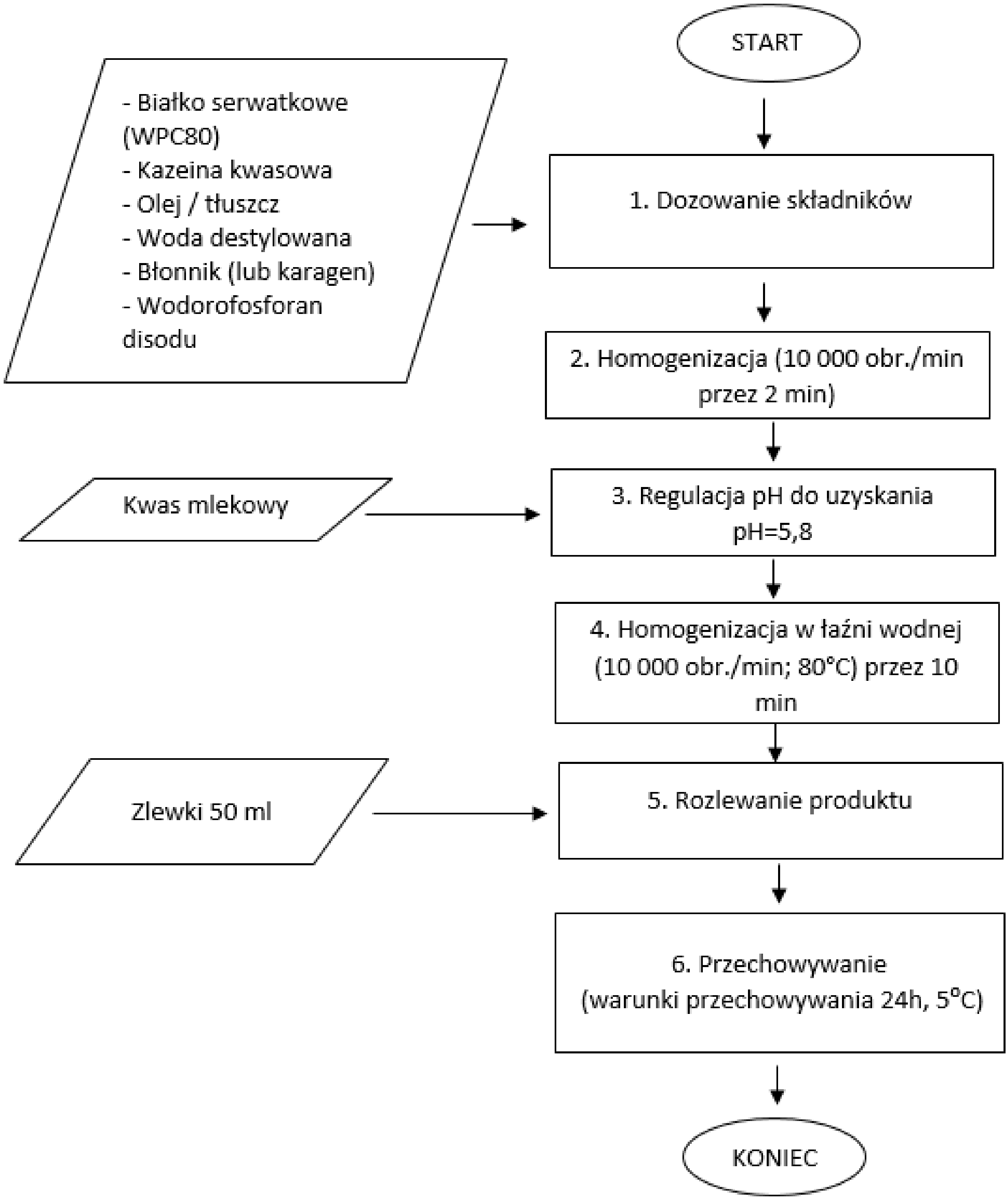
Założenia badawcze weryfikowano poprzez wykonanie serii doświadczeń oraz ich analizę, zgodnie ze schematem przedstawionym w **Tabeli 1.** Efekty weryfikacji przedstawiono w załączonych publikacjach stanowiących przedmiot rozprawy doktorskiej.

Tabela 1. Etapy weryfikacji hipotezy badawczej.

ETAP	ZAŁOŻENIA	PUBLIKACJA
I	**Publikacja I** Gromadzenie materiałów źródłowych i przygotowanie publikacji naukowej opisującej dotychczasową wiedzę na temat technologii produkcji sosów serowych.	Received: 1 August 2019 | Revised: 17 December 2019 | Accepted: 17 December 2019 DOI: 10.1111/jfpe.13364 REVIEW ARTICLE Journal of Food Process Engineering WILEY **Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects** Jagoda O. Szafrańska | Bartosz G. Sołowiej
II	**Publikacja II** Badania dotyczące zastosowania koncentratu białek serwatkowych (WPC80, w ilości 2-8%) jako funkcjonalnego dodatku do sosów serowych.	LWT - Food Science and Technology 127 (2020) 109434 Contents lists available at ScienceDirect LWT - Food Science and Technology journal homepage: www.elsevier.com/locate/lwt ELSEVIER **Effect of whey protein concentrate on physicochemical properties of acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat** Jagoda O. Szafrańska[a], Siemowit Muszyński[b], Bartosz G. Sołowiej[a,*]

III	**Publikacja III** Zastosowane źródła tłuszczu: • olej rzepakowy. Zastosowane błonniki: • cytrusowy, • akacjowy, • ziemniaczany, • bambusowy.	International Journal of Food Science + Technology ifst International Journal of Food Science and Technology 2020, **55**, 1971–1979 Original article **Effect of different fibres on texture, rheological and sensory properties of acid casein processed cheese sauces** Jagoda O. Szafrańska & Bartosz G. Sołowiej*
IV	**Publikacja IV** Zastosowane źródła tłuszczu: • olej kokosowy, • bezwodny tłuszcz mleczny. Zastosowane błonniki: • cytrusowy, • akacjowy, • ziemniaczany, • bambusowy.	*foods* MDPI *Foods* 2021, *10*, 759. https://doi.org/10.3390/foods10040759 https://www.mdpi.com/journal/foods *Article* **The Influence of Dietary Fibers on Physicochemical Properties of Acid Casein Processed Cheese Sauces Obtained with Whey Proteins and Coconut Oil or Anhydrous Milk Fat** Jagoda O. Szafrańska [1], Siemowit Muszyński [2], Igor Tomasevic [3] and Bartosz G. Sołowiej [1,*]

5.2. Formuła badanego sosu serowego



6. Omówienie wyników i dyskusja

6.1. Przedstawienie dotychczasowego stanu wiedzy na temat produkcji sosów serowych

Stan wiedzy na temat legislacji prawnych, obecnie wykorzystywanych półproduktów w produkcji sosów serowych, metod otrzymywania oraz ich właściwości fizykochemicznych i organoleptycznych przedstawiono w **publikacji I (Szafrańska J.O. i Sołowiej B.G., 2020, *Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects.* Journal of Food Process Engineering, 43(4), 3, 1-14.)**. We wspomnianym artykule przeglądowym podjęto próbę usystematyzowania dostępnej wiedzy na temat sosów serowych. Opisano metody produkcji oraz aspekty strukturalno-funkcjonalne z tym związane. W poszczególnych podrozdziałach scharakteryzowano najpopularniejsze składniki wykorzystywane podczas otrzymywania omawianej żywności, jak na przykład ser, proszek serowy, stabilizatory czy hydrokoloidy. Dodatkowo omówiono czynniki fizykochemiczne, mające wpływ na poszczególne komponenty, powodujące zmiany tekstury i smaku, które są istotne z punktu widzenia konsumentów. Dokonano także oceny dostępnej wiedzy na temat prób modyfikacji formuł sosów serowych, które zostały podjęte do tej pory, np. produkcji sosów z dodatkiem olejków eterycznych czy białek soi. Opisano także aspekty mikrobiologiczne odnośnie sosów serowych i ich stabilność podczas przechowywania.

6.2. Badania dotyczące zastosowania koncentratu białek serwatkowych (WPC80) jako funkcjonalnego dodatku do sosów serowych (publikacja II)

Do produkcji sosu serowego najczęściej stosowaną bazą jest ser naturalny. Jego wykorzystanie wpływa na smak, teksturę i konsystencję produktu (Banes i in., 2014). Ze względu na koszty oraz jego okres ważności producenci coraz częściej i chętniej sięgają po różnego rodzaju substytuty lub półprodukty, które mogą być z powodzeniem wykorzystane w produkcji sosów (da Silva i in., 2018). Podczas tworzenia formuły sosu serowego został wykorzystany koncentrat białek serwatkowych WPC80 (ang. whey protein concentrate) w ilości 2-8% jako dodatek funkcjonalny, nadający produktowi odpowiednie cechy fizykochemiczne i organoleptyczne. Na przestrzeni wielu lat udowodniono, że WPC kształtuje właściwości systemów żywnościowych, takie jak smak konsystencja i lepkość, a także wpływa na cechy wizualne oraz reologiczne (Onwulata & Huth, 2009). W związku z powyższym wykonano serię badań mającą na celu określenie czy zastosowanie koncentratu białek serwatkowych (WPC80) oraz jakiej jego ilości wpłynie korzystnie na strukturę sosów serowych i może stanowić potencjalny element ich formuły. W pierwszym etapie doświadczeń wykonano sosy serowe na bazie kazeiny kwasowej, WPC80 oraz karagenu jako substancji stabilizującej o właściwościach emulgujących.

W celu oceny potencjału wykorzystania koncentratu białek serwatkowych wykonano serię doświadczeń. Badano parametry tekstury tj. twardość, przylegalność oraz lepkość. Dokonano oceny parametrów fizykochemicznych (aktywność wody, gęstość), parametrów barwy finalnych wyrobów (Lab, kąt barwy, natężenie koloru). Wyniki przeprowadzonego eksperymentu zostały przedstawione w **publikacji II (Szafrańska J. O., Muszyński S. i Sołowiej B. G., 2020, *Effect of whey protein concentrate on physicochemical properties of acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat.* LWT - Food Science and Technology, 127, 18, 1-7*)*** oraz **Szafrańska J. O., Muszyński S. i Sołowiej B. G., 2019, *Ocena właściwości fizykochemicznych sosów serowych otrzymanych na bazie kazeiny kwasowej i oleju rzepakowego z dodatkiem koncentratu białek serwatkowych.* Przemysł Spożywczy, 73, 36-42**, będącą opisem badań wstępnych dotyczących omawianej formuły.

Tabela 2. Wpływ stężenia WPC80 na cechy tekstury sosów serowych uzyskanych na bazie kazeiny kwasowej z dodatkiem oleju koksowego, rzepakowego lub bezwodnego tłuszczu mlecznego.

Olej/Tłuszcz	Dodatek WPC80 [g/100 g]	Badane cechy tekstury	
		Twardość [N]	Przylegalność (Adhezyjność) [J]
Kokosowy (OCO)	2	$0,11^{a}\pm0,003$	$3,42^{a}\pm0,30$
	3	$0,13^{a} \pm 0,005$	$22,88^{ab}\pm0,88$
	4	$0,18^{b}\pm0,004$	$103,2^{b-d}\pm2,51$
	5	$0,20^{b} \pm 0,007$	$142,09^{cd}\pm1,39$
	6	$0,20^{b} \pm 0,006$	$176,94^{de}\pm0,47$
	7	$0,29^{c}\pm0,017$	$159,03^{de}\pm3,67$
	8	$0,18^{b}\pm0,009$	$62,58^{a-c}\pm0,78$
Mleczny (AMF)	2	$0,11^{a}\pm0,009$	$39,38^{ab}\pm0,63$
	3	$0,15^{b} \pm 0,003$	$102,09^{b-c}\pm1,39$
	4	$0,15^{b} \pm 0,003$	$112,82^{b-c}\pm4,18$
	5	$0,15^{b} \pm 0,001$	$159,12^{de}\pm7,93$
	6	$0,88^{e}\pm0,006$	$232,47^{e}\pm3,67$
	7	$0,93^{f} \pm 0,007$	$384,47^{f}\pm2,68$
	8	$0,98^{f} \pm 0,15$	$392,69^{f}\pm1,1$
Rzepakowy (OR)	2	$0,45^{d}\pm0,02$	$255,14^{e}\pm18,81$
	3	$1,30^{g}\pm0,08$	$447,41^{f}\pm83,92$
	4	$2,61^{i}\pm0,26$	$1127,92^{g}\pm17,76$
	5	$3,26^{j}\pm0,02$	$1334,93^{h}\pm71,69$
	6	$3,37^{jk}\pm0,22$	$1690,90^{i}\pm28,77$
	7	$3,76^{k}\pm0,50$	$1816,29^{j}\pm21,12$
	8	$3,92^{k}\pm0,13$	$2263,60^{k}\pm76,35$

Objaśnienie: Różne litery (a-k) w tej samej kolumnie wskazują na istotne różnice przy $P < 0,05$.

Jedną z pierwszych badanych cech prezentowanej bazy sosu serowego była twardość i przylegalność otrzymanych produktów (Tabela 2.). Statystycznie istotny wzrost twardości zaobserwowano w każdej z badanych serii, jednak w próbkach z dodatkiem bezwodnego tłuszczu mlecznego (AMF) oraz oleju rzepakowego (OR) najwyższe wartości osiągnęły produkty z 8%

dodatkiem WPC80 (P <0,05). Na uzyskane wyniki pomiarów mógł mieć wpływ rodzaj koncentratu białek serwatkowych użytego w eksperymencie. WPC80 charakteryzuje się najniższą wilgotnością oraz najwyższą zawartością białka w porównaniu do WPC35, WPC50 i WPC65 (Chandrapala, 2018). W związku z powyższym większe ilości dodanego WPC80 mogły powodować istotny wzrost twardości produktu. Dodatkowo wyniki pomiarów dla próbek z dodatkiem oleju kokosowego (OCO) świadczą o tym, że na badane cechy mogły mieć wpływ także tłuszcz i oleje będące elementem bazowym. Bezwodny tłuszcz mleczny (AMF) to mieszanina triacylogliceroli składająca się z mniej więcej 60 różnych kwasów tłuszczowych (Dimick i in., 1996). Z kolei olej kokosowy (OCO) zawiera nasycone kwasy tłuszczowe występujące w postaci trójglicerydów, ale większość z nich to średniołańcuchowe kwasy tłuszczowe, które mają pozytywny wpływ na przyspieszenie tempa przemian energetycznych (Gopala i in., 2009) (**publikacja II**). Prezentowane wyniki przylegalności są skorelowane z wartościami twardości badanych produktów. W każdej z testowanych serii następował wzrost przylegalności badanych sosów wraz ze wzrostem dodatku białka serwatkowego. Jedynie w sosach z dodatkiem 8% WPC80 oraz OCO następowało zmniejszenie adhezyjności próbki.

Kolejnymi przeprowadzonymi badaniami były doświadczenia dotyczące modułów: zachowawczego (G′), będącego wynikiem naprężeń związanych z cechami sprężystymi oraz stratności (G″), opisującego naprężenia wynikające z cech lepkich badanych produktów. Zaobserwowano zwiększanie się ich wartości liczbowych wraz ze wzrostem zawartości WPC80 (**publikacja II**), co świadczy o wzmocnieniu struktury żelowej badanych sosów. Wartości modułu G″ nigdy nie były wyższe niż wartości modułu G′. Dodatkowo zauważono, że były one skorelowane z wynikami twardości badanych sosów.

Różnice między wartościami lepkości pozornej występującymi w próbkach były związane z zawartością WPC80 oraz źródłami tłuszczu wykorzystanymi do produkcji sosów. Lepkość pozorna sosów serowych z dodatkiem oleju kokosowego wahała się między 1946 Pa·s (2% dodatek WPC80) - 8300 Pa·s (8% dodatek WPC80), zaś z dodatkiem tłuszczu mlecznego: 2394 Pa·s (2% dodatek WPC80) - 6600 Pa s (6% dodatek WPC80) (P <0,05). Znacząco zmniejszyła się również lepkość produktu z dodatkiem 7 i 8% WPC80 i tłuszczu mlecznego (Odpowiednio 3440 Pa·s i 2518 Pa·s) (P <0,05) (**publikacja II**). W przypadku sosu serowego z wykorzystaniem oleju rzepakowego najwyższą lepkością pozorną charakteryzował się sos z dodatkiem 8% WPC80 (3962 Pa·s), natomiast najniższą z 2% użyciem WPC80 (966 Pa·s).

Tabela 3. Analiza barwy sosów serowych według norm CIE Lab dla próbek otrzymanych na bazie WPC80, kazeiny kwasowej, oleju kokosowego, rzepakowego lub bezwodnego tłuszczu mlecznego.

Źródło tłuszczu/ oleju	Zawartość WPC80 [%]	Wymiary CIE Lab			Kąt barwy	Chroma
		L*	a*	b*	H	C
Kokosowy (OCO)	2	$68,9^{j}\pm1,31$	$-1,21^{k}\pm0,03$	$2,20^{c}\pm0,37$	$150,88^{c}\pm3,53$	$2,51^{b}\pm0,33$
	3	$70,1^{k}\pm 0,13$	$-1,26^{jk}\pm0,06$	$3,31^{de}\pm0,02$	$159,11^{d\text{-}g}\pm0,8$	$3,54^{cd}\pm0,03$
	4	$68,45^{j}\pm0,42$	$-1,26^{jk}\pm0,04$	$3,33^{de}\pm0,15$	$159,24^{d\text{-}g}\pm1,4$	$3,56^{cd}\pm0,12$
	5	$68,3^{j}\pm1,17$	$-1,39^{i}\pm0,01$	$3,18^{d}\pm0,47$	$156,04^{c\text{-}e}\pm3,5$	$3,47^{c}\pm0,42$
	6	$67,36^{ij}\pm0,18$	$-1,36^{ij}\pm0,02$	$4,01^{fg}\pm0,24$	$161,17^{e\text{-}g}\pm1,2$	$4,23^{ef}\pm0,22$
	7	$63,44^{d}\pm0,36$	$-1,67^{cd}\pm0,03$	$4,17^{fg}\pm0,49$	$158,19^{d\text{-}f}\pm0,6$	$4,49^{ef}\pm0,04$
	8	$64,53^{d\text{-}f}\pm0,02$	$-1,79^{ab}\pm0,02$	$4,14^{fg}\pm0,19$	$157,91^{d\text{-}f}\pm0,9$	$4,5^{ef}\pm0,17$
Mleczny (AMF)	2	$66,1^{g\text{-}i}\pm0,21$	$-1,59^{c\text{-}f}\pm0,02$	$3,28^{de}\pm0,02$	$152,67^{cd}\pm0,3$	$3,47^{c}\pm0,01$
	3	$68,02^{j}\pm0,03$	$-1,45^{g\text{-}i}\pm0,01$	$3,90^{ef}\pm0,03$	$159,54^{e\text{-}g}\pm0,3$	$4,16^{de}\pm0,03$
	4	$70,62^{k}\pm3,34$	$-1,55^{d\text{-}g}\pm0,01$	$3,58^{d\text{-}f}\pm0,04$	$156,57^{c\text{-}e}\pm0,3$	$3,9^{c\text{-}e}\pm0,24$
	5	$64,45^{de}\pm0,47$	$-1,48^{f\text{-}i}\pm0,006$	$4,09^{fg}\pm0,03$	$160,08^{e\text{-}g}\pm0,2$	$4,35^{ef}\pm0,03$
	6	$67,32^{h\text{-}j}\pm0,14$	$-1,42^{hi}\pm0,006$	$4,59^{g}\pm0,03$	$162,17^{fg}\pm1,2$	$4,8^{f}\pm0,78$
	7	$65,89^{f\text{-}h}\pm0,51$	$-1,64^{c\text{-}e}\pm0,09$	$6,23^{h}\pm0,22$	$165,3^{g}\pm0,14$	$6,44^{g}\pm0,24$
	8	$64,83^{e\text{-}g}\pm0,07$	$-1,54^{e\text{-}h}\pm0,09$	$6,06^{h}\pm0,1$	$164,96^{g}\pm0,63$	$7,11^{h}\pm0,35$
Rzepakowy (RO)	2	$63,57^{de}\pm0,13$	$-1,59^{c\text{-}f}\pm0,02$	$-0,06^{a}\pm0,19$	$87,75^{a}\pm6,92$	$1,59^{a}\pm0,01$
	3	$65,3^{fg}\pm0,19$	$-1,57^{c\text{-}g}\pm0,01$	$1,47^{b}\pm0,04$	$133,12^{b}\pm0,7$	$2,16^{ab}\pm0,02$
	4	$61,37^{c}\pm0,15$	$-1,59^{c\text{-}f}\pm0,04$	$1,59^{bc}\pm0,21$	$134,83^{b}\pm3,6$	$2,26^{b}\pm0,17$
	5	$61,62^{c}\pm0,04$	$-1,84^{a}\pm0,02$	$3,20^{d}\pm0,64$	$150,07^{c}\pm0,54$	$2,69^{b}\pm0,09$
	6	$56,82^{b}\pm0,15$	$-1,68^{bc}\pm0,06$	$1,82^{bc}\pm0,12$	$137,26^{b}\pm1,07$	$2,47^{b}\pm0,13$
	7	$50,7^{a}\pm0,21$	$-1,69^{bc}\pm0,07$	$4,54^{g}\pm0,48$	$159,45^{e\text{-}g}\pm1,2$	$4,84^{f}\pm0,47$
	8	$63,53^{de}\pm0,02$	$-1,89^{a}\pm0,02$	$4,04^{fg}\pm0,19$	$154,91^{c\text{-}e}\pm0,9$	$4,46^{ef}\pm0,17$

Objaśnienie: Różne litery (a-k) w tej samej kolumnie wskazują na istotne różnice przy $P < 0,05$.

W Tabeli 3 przedstawiono wyniki analizy koloru badanych sosów serowych. Intensywność barwy ocenianych produktów różniła się istotnie od siebie ($P < 0,05$) i można ją było scharakteryzować od jasnej do ciemnej kremowej. Wartości parametru b* w przypadku sosu z dodatkiem oleju kokosowego mieściły się w przedziale 2,2 (dla 2% dodatku WPC80) do 4,17 (dla 7% dodatku WPC80). W produktach na bazie bezwodnego tłuszczu mlecznego: 3,28 (dla 2%

dodatku WPC80) - 6,23 (dla 7% dodatku WPC80), a w sosach z wykorzystaniem oleju rzepakowego: od 1,47 (3% WPC80) do 4,54 (7% WPC80). Jedynie próbka z 2% zawartością WPC80 miała wartość minimalnie ujemną -0,06. Wszystkie badane sosy uzyskały niskie wartości parametru a*, co wskazuje na delikatny zielony odcień. Spośród przebadanych prób, sosy zawierające 7% WPC80 i bezwodny tłuszcz mleczny lub olej rzepakowy charakteryzowały się najwyższym b* i miały odcień najbliższy żółtemu w porównaniu z pozostałymi próbkami. W przypadku produktu otrzymanego na bazie oleju kokosowego największą wartość nasycenia (chroma) można było zaobserwować wśród próbek zawierających 8, 7 i 6% dodatek WPC80, bez znaczącej różnicy między nimi (P <0,05). Jednocześnie próbki te (podobnie jak w przypadku sosów zawierających olej rzepakowy) charakteryzowały się najwyższym b* i najniższymi wartościami parametru a* (więcej odcieni zieleni i żółci).

Testowane sosy cechowały różne kąty barw. Najniższą wartość uzyskała próba z 2% WPC80 a najwyższą z 6% WPC80 (P <0,05). Statystycznie istotne różnice dla L* zmniejszały się wraz ze wzrostem zawartości WPC80 (P <0,05). Sosy otrzymane na bazie bezwodnego tłuszczu mlecznego charakteryzowały się najwyższą zawartością barwy w produkcie. Zwłaszcza w próbce z dodatkiem 8% WPC80 (P <0,05). Każdy z badanych sosów posiadał jasność (L*) w przedziale 64–71 (**publikacja II**).

Aktywność wody w badanych próbach wahała się między 0,992 – 0,998, co przy uzyskanych wynikach może stwarzać warunki dla rozwoju niepożądanej mikroflory, jeżeli nie zapewni się odpowiednich warunków przechowywania, czyli temperatury chłodniczej. Dodatkowo zgodnie z przewidywaniami najwyższymi wartościami gęstości wyróżniały się produkty z największą zawartością białka serwatkowego. Wraz ze wzrostem dodawanego białka zauważono także wahania wartości między poszczególnymi próbami w produktach z olejem rzepakowym, co może świadczyć o niestabilnej strukturze produktów z tym dodatkiem. Z kolei gęstość sosów serowych na bazie OCO oraz OR była większa niż próbek z dodatkiem AMF. Może to być związane z gęstością zastosowanych olejów/tłuszczu. Najwyższe wartości powyżej 1,1 $g \cdot cm^{-3}$ osiągnęły próby z dodatkiem 8% WPC80 oraz oleju kokosowego (**publikacja II**) i rzepakowego.

Na podstawie otrzymanych wyników do kolejnych etapów badań wybrano formułę podstawową zawierającą 6% dodatek koncentratu białek serwatkowych (WPC80).

6.3. Zastosowanie różnych źródeł półproduktów do otrzymywania sosów serowych

6.3.1. Wykorzystanie olejów (rzepakowego i kokosowego) oraz bezwodnego tłuszczu mlecznego jako elementów bazy do otrzymywania sosów serowych

6.3.2. Wykorzystanie błonników (cytrusowego, akacjowego, ziemniaczanego, bambusowego) jako potencjalnych dodatków prozdrowotnych i teksturotwórczych (III i IV publikacja)

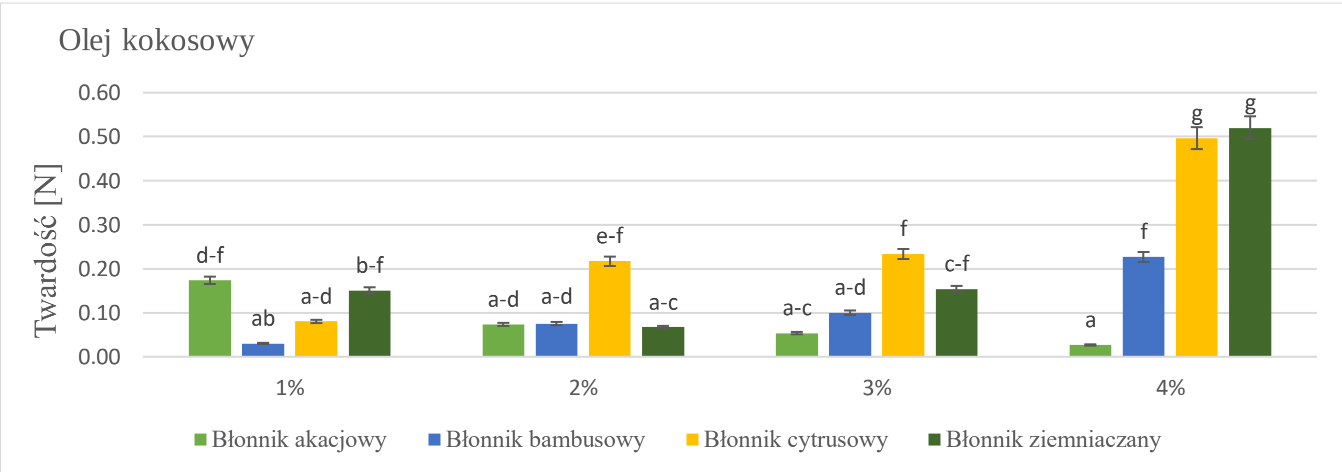
Zazwyczaj w produkcji sosów jako dodatki funkcjonalne stosuje się hydrokoloidy: alginiany, gumę ksantanową, karagen i gumę guar (Hassan i in., 2015). Jednak coraz częściej opisywane komponenty są zastępowane podczas produkcji przez inne składniki, np. błonnik pokarmowy. Zawiera on przydatne dla organizmu substancje odżywcze, takie jak polimery węglowodanowe i polisacharydy (celuloza, hemiceluloza, skrobia, pektyny lub inulina). Nie są one trawione i wchłaniane w jelicie cienkim człowieka, ale stymulują procesy fermentacji w jelicie grubym (Gazi i in., 2017). Dodatkowo właściwości błonnika pokarmowego obejmują skrócenie czasu obecności pokarmu w przewodzie pokarmowym i zwiększenie masy stolca, obniżenie poziomu cholesterolu LDL we krwi oraz poziomu glukozy i insuliny (Phillips, 2013). Pod względem technologicznym produkty spożywcze z dodatkiem błonnika mają korzystniejsze wartości odżywcze, ale także często nadają pokarmom dobre właściwości teksturalne i strukturalne. Przeprowadzono wiele różnych testów, aby obserwować i zdefiniować wpływ różnego rodzaju błonników na produkty spożywcze, na przykład pieczywo lub mięso (Li & Komarek, 2017).

Jako element formuły innowacyjnych sosów serowych zostały wybrane cztery błonniki charakteryzujące się odmiennym składem i cechami funkcjonalnymi: błonnik bambusowy (BF), akacjowy (AF), ziemniaczany (PF) i cytrusowy (CF).

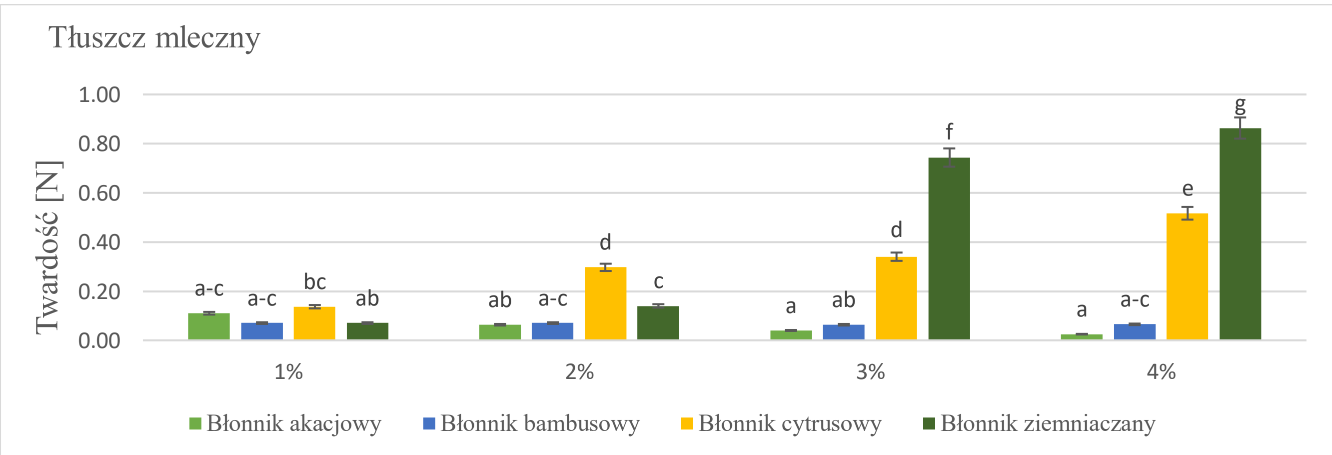
Bambus to roślina, którą można uznać za potencjalne źródło przeciwutleniaczy i związków bioaktywnych. To jeden z najnowszych dodatków w technologii żywności, który stwarza nowe możliwości projektowania produktów wzbogaconych (García-Martínez i in., 2018). Badania dowodzą, że regularne spożywanie żywności na bazie bambusa może zmniejszyć ryzyko chorób przewlekłych, np. chorób układu krążenia, choroby Parkinsona, czy choroby Alzheimera (Nirmala i in., 2018). Z kolei błonnik akacjowy ma udowodnione i rozpoznane działanie prebiotyczne na zdrowie człowieka. Ze względu na bardzo niską wartość kaloryczną nadaje się bardzo dobrze do stosowania jako dodatek dietetyczny w produktach odchudzających. Ponadto niski indeks glikemiczny sprawia, że jest chętnie spożywany przez osoby cierpiące na cukrzycę. pH błonnika akacjowego jest kompatybilne z białkami mleka i z tego powodu doskonale nadaje się on do zastosowań w mleczarstwie, wpływając pozytywnie na właściwości reologiczne końcowych wyrobów (Cherbut i in., 2003; Nakov i in., 2015; Sulieman, 2018). Błonnik ziemniaczany od kilku lat jest przedmiotem zainteresowania naukowców zajmujących się technologią żywności, ale nigdy nie był używany jako składnik sosu serowego. Jest to produkt uboczny podczas otrzymywania skrobi ziemniaczanej (Panasevich i in., 2013). Jego wpływ na względną masę i morfologię jest odmienny u różnych gatunków zwierząt. U szczurów karmionych błonnikiem ziemniaczanym zwiększała się masa jelita cienkiego, ale nie zanotowano wpływu na morfologię dwunastnicy (Antuszewicz i in., 2005; Antuszewicz & Święch, 2006). Z kolei u świń, które były karmione paszą z jego dodatkiem zaobserwowano tendencję do zmniejszania masy dwunastnicy i zmienioną morfologię jelita cienkiego (Pastuszewska i in., 2010). Błonnik cytrusowy znany jest ze swoich właściwości odżywczych i funkcjonalnych. Coraz częściej jest on składnikiem produktów mięsnych, co powoduje zmianę właściwości reologicznych i twardości żywności (Perez-Santaescolastica i in., 2020). Zgodnie z naszą najlepszą wiedzą błonnik ten nigdy nie był używany jako dodatek do sosu serowego. Dane potwierdzają, że może zmniejszyć ryzyko nowotworów, chorób wieńcowych i otyłości (Song i in., 2016). Ma również wysoką zdolność do wiązania wody i nadaje odpowiednią lepkość produktom (Lundberg i in., 2014). Wszystkie przeprowadzone badania i wnioski zostały przedstawione w publikacjach: **Szafrańska J. O. i Sołowiej B. G., 2020, *Effect of different fibres on texture, rheological and sensory properties of acid casein processed cheese sauces.* International Journal of Food Science and Technology, 55(5), 12, 1971–1979 (publikacja III)** oraz **Szafrańska J. O., Muszyński S., Tomasevic I. i Sołowiej B. G., 2021, *The influence of dietary fibers on physicochemical properties of acid casein processed cheese sauces obtained with whey proteins and coconut oil or anhydrous milk fat*. Foods, 10, 759 (publikacja IV).**

Wpływ różnych rodzajów i zawartości błonników dietetycznych na twardość i przylegalność (adhezyjność) otrzymanych sosów serowych na bazie WPC80, kazeiny kwasowej z dodatkiem oleju kokosowego, rzepakowego lub bezwodnego tłuszczu mlecznego zostały przedstawione na wykresach 1a-1c oraz 2a-2c. Sosy z dodatkiem błonnika akacjowego (AF) i każdego testowanego źródła tłuszczu charakteryzowały się mniejszą twardością wraz ze wzrostem ilości dodawanego błonnika ($P < 0{,}05$). Podobną tendencję zaobserwowano w produktach z dodatkiem błonnika ziemniaczanego (PF) oraz oleju rzepakowego (RO). Twardość sosów z dodatkiem błonnika bambusowego (BF) oraz oleju rzepakowego (RO) lub bezwodnego tłuszczu mlecznego (AMF) utrzymywały się na podobnym poziomie niezależnie od zawartości błonnika. Najniższą wartością badanej cechy charakteryzowały się sosy serowe z dodatkiem oleju rzepakowego. Wyniki sugerowały również, że głównym czynnikiem wpływającym na zmianę twardości wszystkich produktów nie był tłuszcz/olej, ale dodane błonniki i ich ilość. W każdej próbce zaobserwowano zwiększenie twardości sosów z dodatkiem CF (błonnik cytrusowy) + OCO (olej kokosowy) (od 0,08 do 0,5 N) CF + AMF (bezwodny tłuszcz mleczny) (od 0,1 do 0,5 N) oraz PF (błonnik ziemniaczany) + OCOC (olej kokosowy) (od 0,07 do 0,5 N) oraz PF (błonnik ziemniaczany) + AMF (bezwodny tłuszcz mleczny) (od 0,06 do 0,9 N) (**publikacja IV**). W badaniach przeprowadzonych na sosach serowych z wykorzystaniem oleju rzepakowego (RO) stwierdzono wahania wartości pomiarów między próbami. Dla sosu z dodatkiem błonnika akacjowego (AF) wartości twardości mieściły się w zakresie od 0,098 N dla produktu z dodatkiem 1% do 0,053 N z dodatkiem 4%. Spośród badanych prób największą twardością charakteryzowały się sosy z błonnikiem cytrusowym (CF). Tylko dla tego testowanego produktu uzyskiwane wartości regularnie zwiększały się wraz z ilością użytego włókna (P <0,05) z 1% (0,47 N) do 4% (1,3 N) (**publikacja III**). Wzrost twardości może wskazywać na to, że ze względu na strukturę wykorzystanych błonników i zawartość poszczególnych frakcji, mniej lub bardziej rozpuszczalnych w wodzie, mogły one wpływać na teksturę sosów (Pastuszewska i in., 2010; Wang, 2010). W przypadku sosów z dodatkiem OCO lub AMF wartości twardości nigdy nie przekraczały 1 N, nawet przy różnej zawartości błonników.

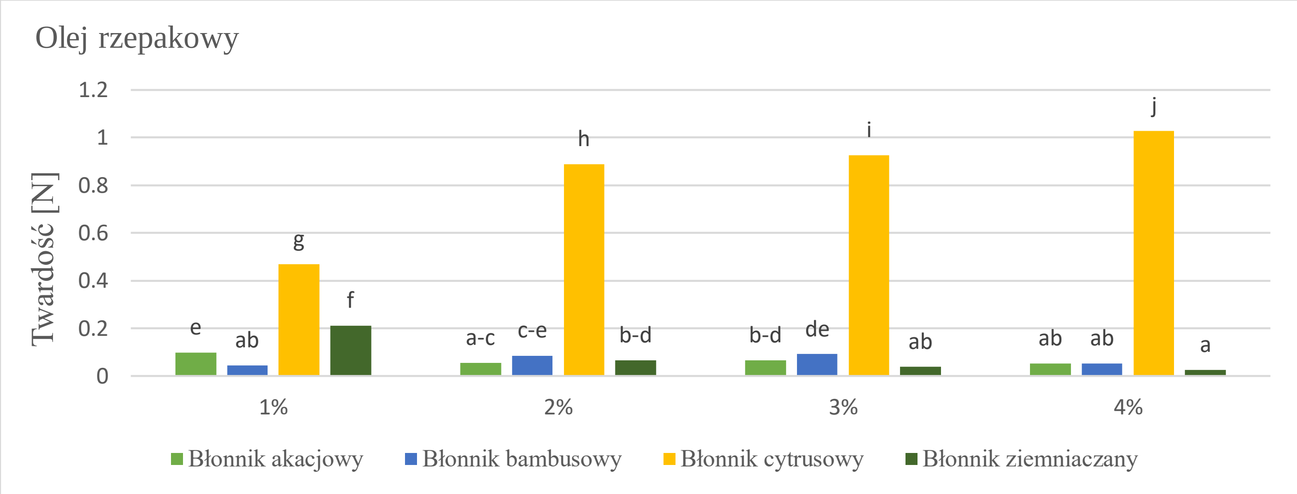
1a)



1b)



1c)

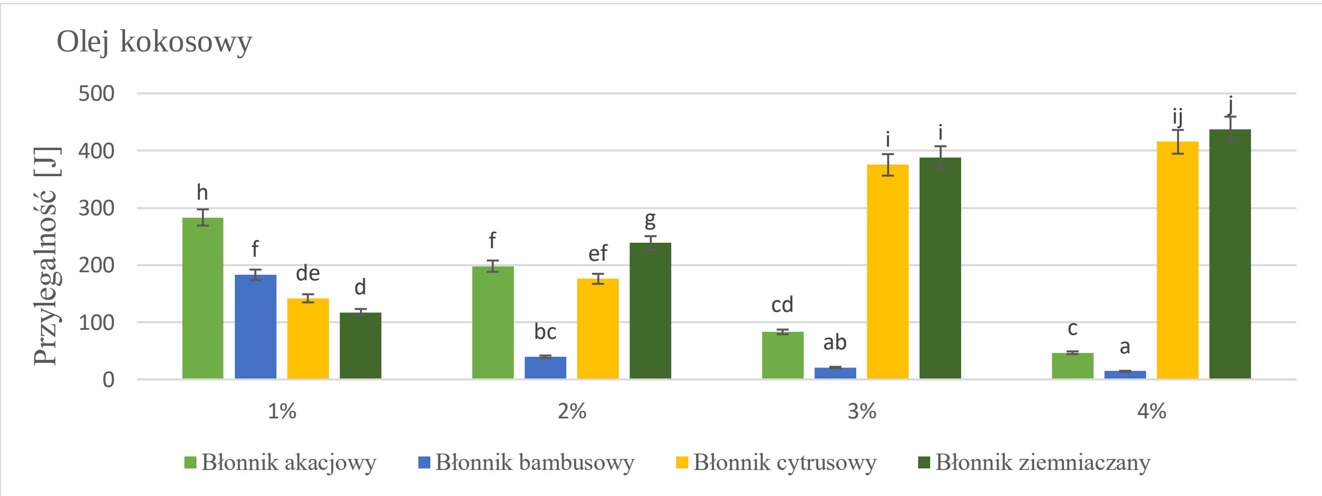


Wykres 1a, 1b, 1c. Wpływ zawartości różnych rodzajów błonnika dietetycznego (błonnika akacjowy – AF, błonnik bambusowy – BF, błonnik cytrusowy – CF, błonnik ziemniaczany - PF) na twardość sosów serowych otrzymanych na bazie kazeiny kwasowej, WPC80 z dodatkiem oleju koksowego, rzepakowego lub bezwodnego tłuszczu mlecznego. Różne litery (a-j) wskazują na istotne różnice przy P <0,05.

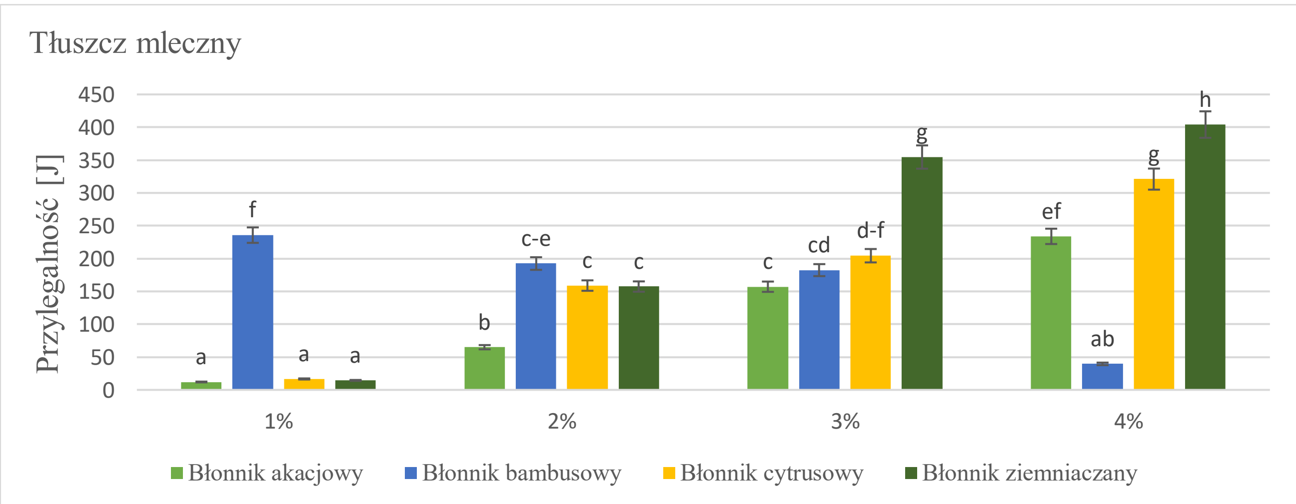
Spośród wszystkich przebadanych próbek najwyższym poziomem przylegalności (adhezyjności) charakteryzował się sos z dodatkiem 4% PF i oleju kokosowego (437 J). Produkty z 4% PF i bezwodnym tłuszczem mlecznym (404 J) oraz 4% CF i olejem kokosowym (415 J) odznaczały się wynikami bardzo zbliżonymi do najwyższej odnotowanej wartości (P <0,05) (**publikacja IV**). W przypadku sosów z dodatkiem oleju rzepakowego najwyższe wartości uzyskał produkt z 1% CF (404 J). Zbliżone do najwyższych wartości wykazały produkty z 1% dodatkiem BF (400 J) i 2% BC (394 J) (**publikacja III**) (Wykresy 2a-2c). Przylegalność w przypadku sosu z dodatkiem BF oraz oleju kokosowego/bezwodnego tłuszczu mlecznego, AF oraz oleju kokosowego/oleju rzepakowego, a także CF i PF oraz oleju rzepakowego zmniejszała się wraz ze wzrostem zawartości błonnika. Przeciwstawne tendencje zauważono w pozostałych badanych próbach (**publikacje III** i **IV**). Analizując uzyskane wyniki można stwierdzić, że na badaną cechę mają wpływ nie tylko wykorzystane błonniki, ale także zastosowane oleje lub tłuszcz. Adhezyjność sosów z dodatkiem AF oraz oleju kokosowego lub rzepakowego systematycznie zmniejszała się wraz ze wzrostem udziału procentowego tego błonnika. W każdym przypadku wartość przyczepności była niższa niż 300 J. Sanchez i in. (2018), analizując dostępną literaturę dotyczącą właściwości błonnika akacjowego zauważyli, że wraz ze wzrostem stężenia AF z 3 do 10% w roztworach wodnych ilość związanej wody zdecydowanie zmniejszyła się (Sanchez i in., 2018). Dodatkowo zaobserwowano rozdzielenie faz badanych produktów, szczególnie w sosach z dodatkiem AF i BF. Stwierdzone różnice między tymi dwoma seriami produktów były związane także z dodatkiem różnymi olejów/tłuszczu. Sosy na bazie oleju kokosowego i BF charakteryzowały się podobny wynikami jak sosy z dodatkiem bezwodnego tłuszczu mlecznego, ale takiego podobieństwa nie zauważono w próbkach z dodatkiem AF (**publikacja IV**).

Skład tłuszczu zwierzęcego zależy od wielu czynników, np. od diety zwierzęcia. Tłuszcze roślinne, takie jak olej rzepakowy, są mniej zmienne. Bezwodny tłuszcz mleczny jest mieszaniną triacylogliceroli i posiada wyjątkowe właściwości termiczne i chemiczne (Dimick i in., 1996). Fizyczne właściwości tłuszczu, które wpływają na cechy żywności, do której są dodawane, dotyczą głównie zmian fazowych zachodzących podczas przejść, np. ze stanu ciekłego w stały lub stały w ciekły (Kaylegian i in., 1993). Bezwodny tłuszcz mleczny jest produktem końcowym po prawie całkowitym wyeliminowaniu wody i masy beztłuszczowej (Timms, 1994). Dodatkowo niewielka zawartość fosfolipidów (około 0,01%) (Barry i in., 2016) może być związana ze zmianami przylegalności w poszczególnych sosach.

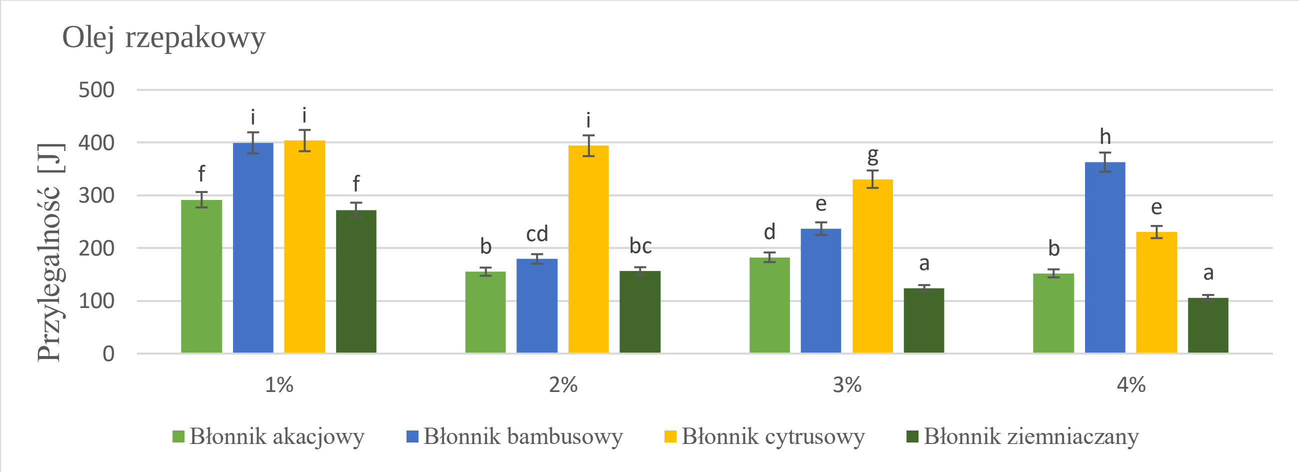
2a)



2b)



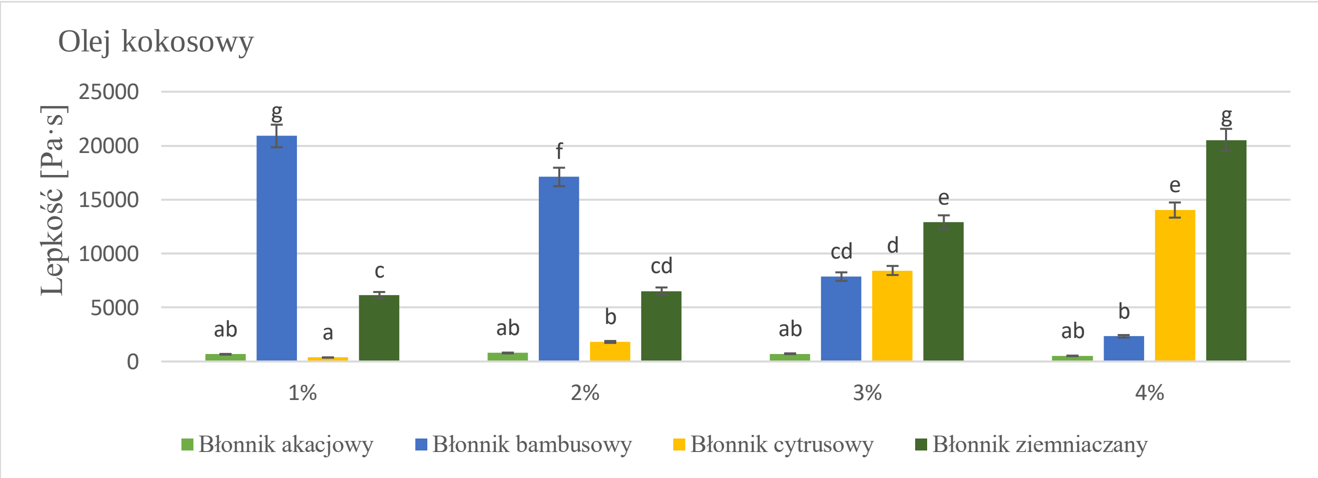
2c)



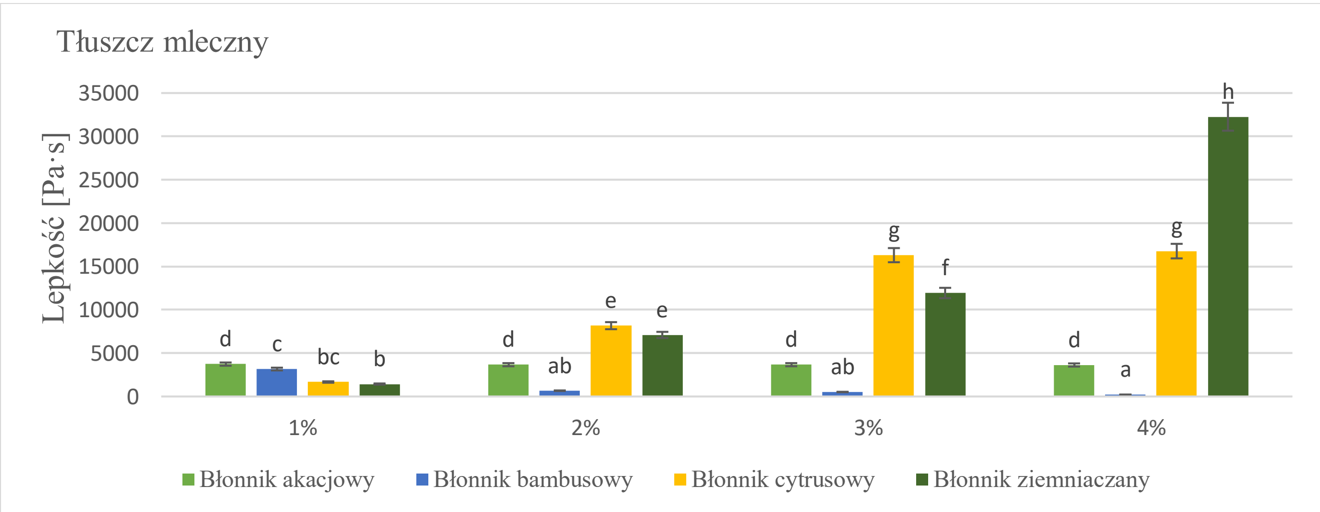
Wykresy 2a, 2b, 2c. Wpływ zawartości różnych rodzajów błonnika dietetycznego (błonnika akacjowy – AF, błonnik bambusowy – BF, błonnik cytrusowy – CF, błonnik ziemniaczany - PF) na przylegalność sosów serowych otrzymanych na bazie kazeiny kwasowej, WPC80, z dodatkiem oleju koksowego, rzepakowego lub bezwodnego tłuszczu mlecznego. Różne litery (a-j) wskazują na istotne różnice przy P <0,05.

Na wykresach 3a-3c zilustrowano wartości lepkości pozornej badanych produktów na bazie kazeiny kwasowej, WPC80, oleju kokosowego (Wyk. 3a), bezwodnego tłuszczu mlecznego (Wyk. 3b), oleju rzepakowego (Wyk. 3c) z dodatkiem różnych błonników dietetycznych (akacjowego, bambusowego, cytrusowego i ziemniaczanego). Ogólnie lepkość pozorna sosów serowych z dodatkiem PF zwiększała się w każdej testowanej serii. Podobnie jak w przypadku próbek z dodatkiem CF oraz oleju kokosowego/bezwodnego tłuszczu mlecznego i AF z dodatkiem oleju rzepakowego. W pozostałych seriach wartości te zmniejszały się wraz ze wzrostem ilości używanego błonnika lub utrzymywały się na tym samym poziomie (AF + olej kokosowy/bezwodny tłuszcz mleczny oraz BF + olej rzepakowy) (**publikacje III** i **IV**). Sosy z bezwodnym tłuszczem mlecznym charakteryzowały się wyższymi wartościami lepkości pozornej niż w przypadku pozostałych badanych olejów. Zasadniczo interakcje między stałym składnikiem produktu a wykorzystywanymi olejami/tłuszczem obejmują powlekanie cząstek matrycy żywnościowej. Tłuszcz wnika w nią i powoduje efekt lepkości (Kaylegian i in., 1993). Może to sugerować, że poszczególne oleje oraz tłuszcz lepiej wpływają na strukturę badanego sosu, przez co niektóre produkty uzyskały wyższe wartości lepkości. Zaobserwowano również, że lepkość bezwodnego tłuszczu mlecznego jest związana z takimi czynnikami, jak szybkość ścinania, temperatura, czy pH (Marangoni i in., 2012) (**publikacja IV**). Kolejnym czynnikiem, związanym z otrzymanymi wartościami były zastosowane błonniki. Gdy masa cząsteczkowa oraz długość łańcucha błonnika zwiększa się, lepkość danego roztworu również ulega zwiększeniu. Błonniki rozpuszczalne charakteryzowały się stosunkowo dużą lepkością w porównaniu z błonnikami nierozpuszczalnymi (Fabek i in., 2014). Na przykład silnie rozgałęziona struktura molekularna i niska masa cząsteczkowa błonnika akacjowego może powodować zmianę lepkości produktu (Milani & Maleki, 2012). Podczas przeprowadzanych badań zaobserwowano, że sosy z błonnikiem akacjowym miały bardziej płynną strukturę, a w niektórych przypadkach odnotowano rozwarstwienie produktu końcowego. Innym błonnikiem charakteryzującym się dużą zdolnością zatrzymywania wody jest błonnik bambusowy (Seçkin & Baladura, 2012). Z kolei błonnik cytrusowy posiada w swojej strukturze głównie pektyny i celulozy. Ze względu na kwasowy charakter składników pektyny, może on wpływać na lepkość produktu, a także na jego właściwości żelujące (Lundberg i in., 2014; Willats i in., 2006) (**publikacja III**).

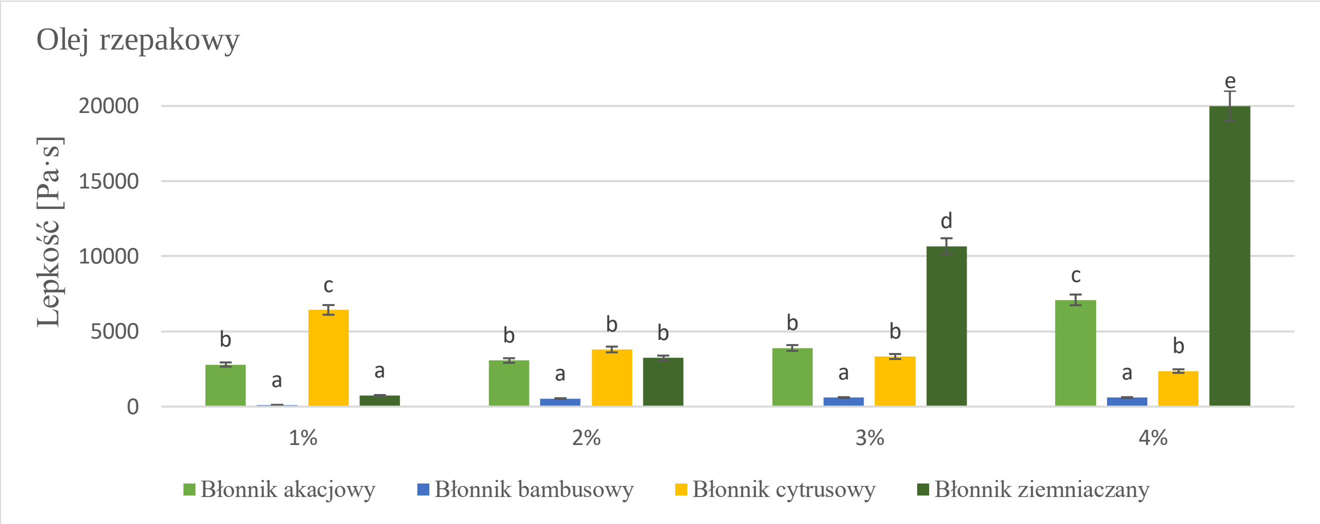
3a)



3b)



3c)



Wykresy 3a, 3b, 3c. Wpływ zawartości różnych rodzajów błonnika dietetycznego (błonnika akacjowy – AF, błonnik bambusowy – BF, błonnik cytrusowy – CF, błonnik ziemniaczany - PF) na lepkość pozorną sosów serowych otrzymanych na bazie kazeiny kwasowej, WPC80, z dodatkiem oleju koksowego, rzepakowego lub bezwodnego tłuszczu mlecznego. Różne litery (a-e) wskazują na istotne różnice przy P <0,05.

W **publikacjach III** oraz **IV** przedstawiono wpływ rodzaju oraz zawartości błonnika pokarmowego na moduły opisujące naprężenia wynikające z cech sprężystych (G′) i cech lepkich (G″) sosów serowych. W badanych produktach z dodatkiem oleju rzepakowego oraz BF i PF wartości opisywanych cech zwiększały się wraz ze wzrostem ilości błonnika (1–4%), co świadczy o wzmocnieniu struktury żelowej sosów. W próbkach z dodatkiem AF uzyskane wyniki modułów zwiększały się (1–2%), zaś w sosach z dodatkiem 3–4 % błonnika – zmniejszały się. We wszystkich badanych sosach wartości G′ były zawsze wyższe niż G″. W każdej badanej próbie z 1% dodatkiem błonnika wyniki G′ i G″ były najniższe, co wskazuje, że struktura żelowa tych sosów serowych tworzyła najmniej elastyczny system (**publikacja III**). Z kolei w produktach na bazie oleju kokosowego i bezwodnego tłuszczu mlecznego wyniki pomiarów dla modułów G′ i G″ były bardzo zróżnicowane. W przypadku testowanych sosów z PF i bezwodnym tłuszczem mlecznym lub olejem kokosowym (2–3%) oraz BF i bezwodnym tłuszczem mlecznym (1–4%), wraz z ilością dodanego błonnika zwiększała się wartość ww. cech (**publikacja IV**). Najwyższe otrzymane wyniki pomiarów w produktach są zgodne z przeprowadzonymi obserwacjami. W sosach, w których opisywane wartości zmniejszały się, zaobserwowano osłabienie struktury produktu, mimo że każda testowana próbka do końca eksperymentu wykazywała właściwości słabego żelu (G′ >G″). Zaobserwowano, że wartości modułów były wyższe w sosach zawierających BF i PF. Może to wynikać z faktu, że w swej strukturze posiadają mniejszą ilość frakcji rozpuszczalnych w wodzie. Produkty o wyższej zawartości pektyn posiadają grubszą sieć żelową i charakteryzują się twardszą strukturą (Löfgren i in., 2002).

W Tabeli 4 przedstawiono wyniki analizy kolorów uzyskane za pomocą komputerowego systemu wizyjnego (ang. CVS - Computer Vision System). Jedną z najważniejszych zmiennych wpływających na preferencje konsumentów jest barwa. Dlatego tak ważne jest, aby przygotować produkt, który sprosta ich wymaganiom. Intensywność barwy sosów serowych była istotnie różna pomiędzy badanymi próbkami (P <0,05) i można było określić jej barwę od kremowo-białej do kremowo-żółtej, ponieważ wartość b* w sosach z dodatkiem oleju kokosowego i AF, BF oraz CF charakteryzowały się niższymi wartościami niż produkty na bazie bezwodnego tłuszczu mlecznego i oleju rzepakowego. Spośród wszystkich przebadanych próbek, sosy z dodatkiem bezwodnego tłuszczu mlecznego odznaczały się najwyższymi wartościami b*, a ich barwa posiadała najwięcej żółtych tonów w porównaniu z pozostałymi próbkami. Wszystkie badane serie miały dodatnie wartości parametru a*, co wskazywało na lekki odcień czerwieni. Jasność (L*) każdej z mierzonych próbek wahała się od 79 do około 89. Statystycznie istotne różnice dla L* zaobserwowano między próbkami w każdej grupie produktów (P <0,05). Na barwę badanych produktów największy wpływ miały wykorzystane do ich otrzymania oleje i tłuszcz, zaś błonniki nie wpłynęły istotnie na barwę testowanych produktów. Błonnik bambusowy użyty do przygotowania sosów posiadał biały kolor, natomiast błonniki akacjowy i cytrusowy charakteryzowały się kremowo-białymi odcieniami. Jedynie błonnik ziemniaczany cechował się widocznymi jasnobrązowymi drobinami, których barwa nie była widoczna w finalnym produkcie (**publikacja IV**).

Aby uzyskać pełny opis barwy sosów, zbadano dodatkowo dwa kolejne parametry: kąt barwy oraz nasycenie. Najniższą wartością kąta barwy charakteryzowały się próbki z olejem kokosowym oraz PF (1-3%) (P <0.05). Pomiary wykazały, że barwa sosów mieściła się w przedziale 5–38, co odpowiada barwie pomarańczowej. Drugim parametrem wyglądu opisującym opracowywany produkt jest nasycenie barwy. W przypadku sosu otrzymanego z dodatkiem oleju rzepakowego największe nasycenia barwy zaobserwowano wśród próbek z dodatkiem 1–3% AF.

Tabela 4. Wpływ różnej zwartości błonników dietetycznych (akacjowego – AF, bambusowego – BF, cytrusowego – CF oraz ziemniaczanego – PF) na barwę (standardy CIE Lab) sosów serowych otrzymanych na bazie kazeiny, WPC80 oraz olejów: rzepakowego, kokosowego lub bezwodnego tłuszczu mlecznego.

Błonnik/ olej/ tłuszcz		L*				a*				b*				Chroma				Kąt barwy			
		Zawartość błonnika (%)				Zawartość błonnika (%)				Zawartość błonnika (%)				Zawartość błonnika (%)				Zawartość błonnika (%)			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Olej kokosowy	AF	85,0^{f-i} ±1,5	85,9^{h-k} ±0,9	86,9^{j-u} ±0,4	85,0^{f-i} ±0,6	6,14^{u} ±0,69	5,71^{o-u} ±0,49	4,29^{j-m} ±0,49	5,57^{n-u} ±0,53	19,4^{k-n} ±2,2	19,9^{k-n} ±1,6	7,86^{d-f} ±1,21	14,7^{gh} ±1,5	20,4^{kl} ±2,3	20,7^{kl} ±1,6	8,96^{fg} ±1,23	15,7^{h-j} ±1,5	17,6^{j-o} ±1,6	16,1^{g-n} ±1,1	28,8^{r} ±3,0	20,8^{n-u} ±2,1
	BF	88,9^{u} ±0,4	88,6^{ou} ±0,5	87,1^{k-u} ±1,5	87,1^{k-u} ±0,9	2,43^{d-g} ±0,53	2,43^{d-g} ±0,53	2,14^{d-f} ±0,69	3,71^{h-k} ±0,49	9,57^{f} ±0,53	9,29^{f} ±0,76	7,14^{d-f} ±2,11	9,29^{f} ±0,95	9,88^{fg} ±0,56	9,61^{fg} ±0,81	7,47^{c-g} ±2,19	10,0^{g} ±0,9	14,2^{e-k} ±3,0	14,6^{e-l} ±2,7	16,8^{h-o} ±3,3	21,9^{ou} ±3,1
	CF	88.1^{n-u} ±0,7	87.6^{n-u} ±0,5	86.6^{i-u} ±0,5	86.4^{i-o} ±0,8	1,71^{c-f} ±0,76	2,00^{d-f} ±0,82	1,85^{d-f} ±0,69	2,71^{d-h} ±0,76	8,57^{ef} ±0,53	9,00^{f} ±0,58	8,14^{ef} ±1,99	9,71^{f} ±0,76	8,77^{e-g} ±0,57	9,25^{fg} 0,59	8,39^{d-g} ±1,99	10,1^{g} ±0,7	11,3^{b-f} ±4,7	12,5^{c-h} ±5,0	13,48^{e-j} ±5,8	15,7^{f-m} ±4,8
	PF	81,1^{a-d} ±1,5	80,0^{ab} ±0,1	79,6^{a} ±2,5	83,0^{d-f} ±1,2	3,00^{e-h} ±0,58	2,71^{d-h} ±0,76	5,43^{m-u} ±1,27	4,57^{k-o} ±0,53	26,3^{u} ±1,5	26,9^{u} ±1,9	24,1^{ou} ±2,9	8,00^{ef} ±0,82	26,5^{n} ±1,5	27,0^{n} ±1,9	24,7^{m-n} ±3,0	9,22^{fg} ±0,93	6,50^{ab} ±1,19	5,71^{a} ±1,23	12,5^{c-h} ±1,6	29,7^{s} ±1,9
Tłuszcz mleczny	AF	85,6^{g-k} ±1,0	85,0^{f-i} ±1,6	82,6^{c-e} ±1,5	82,0^{b-e} ±0,6	3,57^{g-k} ±0,79	3,71^{h-k} ±0,76	4,43^{k-n} ±0,79	7,86^{p} ±0,38	20,3^{l-n} ±2,5	21,6^{m-o} ±1,9	26,9^{u} ±1,6	23,7^{no} ±1,6	20,6^{kl} ±2,6	21,9^{l-m} ±1,9	27,2^{n} ±1,6	25,0^{m-n} ±1,6	9,90^{a-e} ±1,50	9,77^{a-e} ±1,84	9,37^{a-d} ±1,68	18,4^{l-o} ±0,8
	BF	88,1^{n-u} ±1,6	86,9^{j-u} ±0,9	87,3^{l-u} ±0,8	87,9^{n-u} ±1,2	2,57^{d-h} ±0,53	4,14^{i-l} ±0,38	2,00^{d-f} ±0,01	2,14^{d-f} ±0,38	21,3^{m-o} ±4,1	14,7^{gh} ±1,7	16,6^{h-k} ±1,0	16,9^{h-l} ±1,7	21,4^{l} ±4,1	15,3^{hi} ±1,7	16,7^{h-j} ±1,0	17,0^{h-j} ±1,7	7,00^{ab} ±1,67	15,8^{f-n} ±1,4	6,90^{ab} ±0,41	7,32^{ab} ±1,59
	CF	85,3^{f-j} ±0,5	83,4^{d-g} ±1,0	80,3^{a-c} ±0,5	79,7^{ab} ±0,8	4,71^{k-o} ±0,49	5,29^{l-u} ±0,76	5,71^{o-u} ±0,49	5,57^{n-u} ±0,79	14,9^{gh} ±1,1	16,7^{h-k} ±1,1	17,7^{i-l} ±1,1	18,1^{j-n} ±0,7	15,6^{hi} ±1,1	16,9^{h-j} ±1,5	17,7^{i-k} ±1,1	19,0^{j-l} ±0,6	17,6^{j-o} ±1,5	18,2^{k-o} ±1,6	18,9^{m-o} ±1,5	17,1^{i-o} ±2,6
	PF	88,0^{n-u} ±1,4	84,3^{e-h} ±1,1	81,9^{a-d} ±1,3	80,0^{ab} ±0,8	3,14^{f-j} ±0,38	4,43^{k-n} ±0,53	5,00^{l-u} ±0,82	5,57^{n-u} ±0,53	17,6^{i-l} ±1,0	13,0^{g} ±1,3	13,1^{g} ±1,6	15,7^{g-i} ±1,0	17,9^{i-k} ±1,0	13,7^{h} ±1,3	14,1^{h} ±1,7	16,7^{h-j} ±1,0	10,1^{a-e} ±0,9	18,9^{m-o} ±1,9	20,8^{n-u} ±1,5	19,5^{n-o} ±1,2
Olej rzepakowy	AF	86,4^{i-o} ±0,92	88,7^{ou} ±1,22	88,6^{ou} ±0,26	86,2^{i-m} ±0,22	1,61^{c-f} ±0,11	1,69^{c-f} ±0,02	1,1^{b-d} ±0,02	1,1^{b-d} ±0,03	1,47^{a} ±0,36	1,52^{a} ±0,19	1,86^{a} ±0,16	1,92^{ab} ±0,27	2,19^{a} ±0,17	2,27^{a} ±0,13	2,16^{a} ±0,15	2,20^{a} ±0,25	38,06^{w} ±1,77	34,89^{u} ±3.16	30,56^{t} ±1,72	26,39^{p} ±2,48
	BF	82,8^{c-f} ±2,75	86,1^{i-l} ±0,06	87,3^{l-u} ±0,18	87,4^{m-u} ±1,02	1,1^{b-d} ±0,16	1,28^{b-d} ±0,03	1,1^{b-d} ±0,02	0,98^{a-c} ±0,02	2,06^{ab} ±0,59	5,61^{b-e} ±0,05	6,28^{c-f} ±0,08	6,82^{c-f} ±0,16	2,37^{ab} ±0,47	5,75^{a-f} ±0,05	6,38^{a-g} ±0,08	7,40^{b-g} ±0,44	23,4^{up} ±1,63	12,86^{d-i} ±0,15	9,96^{a-e} ±0,04	8,46^{a-c} ±0,26
	CF	84,1^{e-h} ±0,93	83,2^{d-g} ±0,39	81,7^{a-d} ±0,55	80,7^{a-d} ±0,25	1,38^{b-e} ±0,11	1,81^{d-f} ±0,02	1,64^{c-f} ±0,02	1,48^{b-e} ±0,02	4,19^{b-d} ±0,32	3,44 $^{b-c}$ ±0,13	7,48^{d-e} ±0,10	8,33^{ef} ±0,10	4,41^{a-d} ±0,34	4,55^{a-e} ±0,47	7,66^{c-g} ±0,11	8,46^{d-g} ±0,10	18,2^{k-o} ±0,22	16,4^{h-n} ±0,35	12,39^{c-g} ±0,09	10,07^{a-e} ±0,18
	PF	88,9^{u} ±0,13	86,3^{i-n} ±4,51	86,1^{i-l} ±0,06	87,3^{l-u} ±0,18	0,8^{ab} ±0,07	0,7^{a} ±0,17	1,3^{b-d} ±0,03	1,1^{b-d} ±0,02	3,21^{b-c} ±0.03	2,33^{ab} ±0,18	5,61^{b-e} ±0,05	6,28^{c-f} ±0,08	3,32^{a-c} ±0,01	4,45^{a-d} ±0,13	5,75^{a-f} ±0,05	6,38^{a-g} ±0,08	14,6^{e-l} ±1,27	13,48^{e-j} ±0,6	12,86^{d-i} ±0,15	9,96^{a-e} ±0,04

Objaśnienie: Różne litery (a-u) w tej samej kolumnie wskazują na istotne różnice przy P <0,05.

Tabela 5. Wpływ różnej zwartości błonników dietetycznych (akacjowego – AF, bambusowego – BF, cytrusowego – CF oraz ziemniaczanego – PF) na parametry modułów G′ (Pa) i G″ (Pa), tan (δ) oraz granicę płynięcia (yield stress) sosów serowych otrzymanych na bazie kazeiny, WPC80 oraz olejów: rzepakowego, kokosowego lub bezwodnego tłuszczu mlecznego.

Olej/ tłuszcz	**Błonnik**	**G′ (Pa)** Zawartość błonnika (%)				**G″ (Pa)** Zawartość błonnika (%)				**tg (δ)** Zawartość błonnika (%)				**Granica płynięcia (yield stress) (Pa)** Zawartość błonnika (%)			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Olej kokosowy (OCO)	AF	$3,5^{a}$ ±0,69	$0,70^{a}$ ±0,12	$60,1^{b}$ ±8,3	785^{j} ±79	$1,17^{a}$ ±0,55	$0,55^{a}$ ±0,09	$43,01^{b-d}$ ±5,6	361^{lm} ±74	$0,40^{k-o}$ ±0,22	$0,79^{u}$ ±0,10	$0,72^{t}$ ±0,08	$0,47^{o}$ ±0,12	601^{k} ±1	206^{g} ±1	212^{g} ±1	$1,04^{a}$ ±0,03
	BF	$13,4^{a}$ ±3,5	568^{h} ±7	383^{fg} ±1	3774^{v} ±10	$9,7^{ab}$ ±1	278^{k} ±28	134^{hi} ±1	1235^{v} ±25	$0,70^{s}$ ±0,01	$0,49^{u}$ ±0,05	$0,35^{h-l}$ ±0,01	$0,33^{f-j}$ ±0,01	$1,82^{a}$ ±0,01	$40,3^{cd}$ ±0,2	$81,5^{e}$ ±1,6	407^{i} ±2
	CF	$11,4^{a}$ ±0,1	2703^{r} ±211	546^{h} ±22	3122^{t} ±22	$7,68^{ab}$ ±0,14	775^{p} ±66	181^{ij} ±32	950^{rs} ±5	$0,67^{r}$ ±0,01	$0,29^{c-f}$ ±0,05	$0,33^{f-j}$ ±0,07	$0,30^{d-g}$ ±0,01	$47,9^{d}$ ±0,1	415^{i} ±1	894^{m} ±12	963^{n} ±12
	PF	$23,8^{ab}$ ±8,4	951^{l} ±13	2824^{s} ±38	$13,8^{a}$ ±2,1	$16,7^{a-c}$ ±1,4	394^{n} ±43	874^{q} ±12	$5,4^{ab}$ ±5,6	$0,70^{s}$ ±0,07	$0,41^{l-o}$ ±0,05	$0,31^{d-h}$ ±0,01	$0,39^{k-o}$ ±0,04	205^{g} ±1	415^{i} ±3	1254^{p} ±18	2973^{r} ±46
Tłuszcz mleczny (AMF)	AF	1158^{m} ±36	844^{k} ±10	633^{i} ±4	177^{c} ±3	411^{n} ±6	322^{lm} ±11	210^{j} ±2	74^{df} ±7	$0,35^{h-l}$ ±0,01	$0,38^{j-o}$ ±0,01	$0,33^{f-j}$ ±0,01	$0,42^{m-o}$ ±0,04	$17,3^{a-c}$ ±0,3	$16,1^{a-c}$ ±0,4	$6,42^{a}$ ±0,4	$0,66^{a}$ ±0,36
	BF	$6,12^{a}$ ±0,09	1744^{o} ±13	2650^{q} ±30	4717^{y} ±117	$3,82^{ab}$ ±0,12	906^{r} ±11	944^{rs} ±8	1922^{z} ±217	$0,62^{q}$ ±0,01	$0,52^{p}$ ±0,01	$0,32^{e-i}$ ±0,01	$0,41^{l-o}$ ±0,05	108^{e} ±3	161^{f} ±3	219^{g} ±1	$6,81^{a}$ ±0,01
	CF	$29,9^{ab}$ ±0,02	3451^{u} ±77	336^{e} ±11	2022^{u} ±10	$7,50^{ab}$ ±0,05	769^{p} ±15	116^{gh} ±2	523^{ou} ±4	$0,25^{ab}$ ±0,01	$0,22^{a}$ ±0,01	$0,34^{g-k}$ ±0,01	$0,26^{ab}$ ±0,01	$6,81^{a}$ ±0,01	338^{h} ±2	562^{j} ±5	1217^{u} ±13
	PF	3773^{v} ±10	1269^{n} ±57	2511^{p} ±16	$19,8^{ab}$ ±3,1	1177^{u} ±38	573^{ou} ±15	770^{p} ±4	$5,2^{ab}$ ±1,8	$0,31^{d-h}$ ±0,01	$0,45^{no}$ ±0,02	$0,31^{d-h}$ ±0,01	$0,26^{ab}$ ±0,05	429^{i} ±2	706^{l} ±5	1143^{o} ±4	1835^{q} ±1
Olej rzepakowy (RO)	AF	406^{g} ±2	914^{l} ±39	786^{j} ±2	346^{ef} ±1	146^{i} ±3	727^{up} ±9	246^{jk} ±3	119^{gh} ±2	$0,35^{h-l}$ ±0,01	$0,38^{j-o}$ ±0,009	$0,31^{d-h}$ ±0,005	$0,34^{g-k}$ ±0,006	$1,268^{a}$ ±0,006	$1,112^{a}$ ±0,001	$0,104^{a}$ ±0,001	$0,093^{a}$ ±0,001
	BF	681^{i} ±3	905^{l} ±3	2640^{q} ±48	4282^{x} ±166	208^{j} ±1	310^{l} ±3	1073^{t} ±6	1608^{y} ±17	$0,30^{d-g}$ ±0,009	$0,32^{e-i}$ ±0,01	$0,34^{g-k}$ ±0,02	$0,33^{f-j}$ ±0,02	$0,292^{a}$ ±0,001	$3,59^{a}$ ±0,002	$15,24^{a-c}$ ±0,05	$16,26^{a-c}$ ±0,16
	CF	248^{d} ±1	210^{c} ±0,4	257^{d} ±1	225^{d} ±1	87^{fg} ±1	53^{cd} ±1	62^{de} ±1	57^{cd} ±0,5	$0,36^{i-m}$ ±0,003	$0,36^{i-m}$ ±0,006	$0,22^{a}$ ±0,006	$0,27^{bc}$ ±0,003	$4,64^{a}$ ±0,06	$7,02^{a}$ ±0,001	$10,32^{a}$ ±0,006	$15,57^{a-c}$ ±0,02
	PF	1778^{o} ±5	3858^{w} ±23	4741^{y} ±50	5993^{z} ±32	501^{o} ±5	1300^{w} ±10	$14184^{a'}$ ±14	1519^{x} ±5	$0,28^{b-d}$ ±0,002	$0,29^{c-e}$ ±0,001	$0,29^{c-e}$ ±0,009	$0,25^{ab}$ ±0,009	$3,28^{a}$ ±0,007	$12,01^{ab}$ ±0,006	$37,13^{b-d}$ ±0,12	$104,8^{e}$ ±0,1

Objaśnienie: Różne litery (a-z) w tej samej kolumnie wskazują na istotne różnice przy P <0,05.

W Tabeli 5 przedstawiono wpływ zawartości poszczególnych rodzajów błonnika pokarmowego na właściwości lepkosprężyste sosów serowych z dodatkiem oleju kokosowego i bezwodnego tłuszczu mlecznego (**publikacja IV**) oraz oleju rzepakowego (**publikacja III**). Wyniki pomiarów modułów G′ i G″ były zróżnicowane. W przypadku testowanych sosów: BF + AMF/OCO/RO (1–4%) i PF + RO (1–4%), wraz ze wzrostem ilości dodanego błonnika zwiększała się wartość opisywanych modułów, co świadczy o wzmocnieniu struktury żelowej badanych produktów. Przedstawione wyniki wskazują na to, że badane sosy mają sieci zależne od odkształceń. Wykazują inną tendencję do płynięcia niż prawdziwe żele (Clegg, 1995). W próbkach z AF + AMF (1–4%) i BF + OCO (1–3%) AF+RO (2-4%) zaobserwowano zmniejszenie opisanych cech wraz z ilością dodawanego błonnika.

Wartości modułu zachowawczego (G′) były wyższe od modułu stratności (G″) we wszystkich testowanych próbkach. Sugeruje to, że przygotowane próbki podczas całego pomiaru wykazywały właściwości sprężyste. W przypadku sosów z dodatkiem oleju rzepakowego wartości modułów były wyższe w sosach z dodatkiem błonników: bambusowego (BF) i ziemniaczanego (PF). Taki wynik może być spowodowany faktem, że PF i BF zawierają mniej frakcji rozpuszczalnych w wodzie (**publikacja III**). Ponadto odnotowano zależność w zmniejszaniu i zwiększaniu wartości między badanymi modułami a twardością sosów. W przypadku sosów z dodatkiem AMF, produkty z 1% AF i PF miały najwyższe wartości G′ i G″, co oznacza, że ich struktura żelowa była najsilniejsza i tworzyła bardziej elastyczny system niż produkty z większą ilością dodanego błonnika. W innych produktach ta tendencja uległa odwróceniu. Najwyższe wartości modułu G′ zaobserwowano w 4% sosie PF + RO (5993 Pa), a najniższe w 2% AF + OCO (0,70 Pa) i są zgodne z naszymi obserwacjami. Może to być spowodowane tym, że błonnik akacjowy ma większą ilość frakcji rozpuszczalnych w wodzie. Większa zawartość frakcji nierozpuszczalnej użytego błonnika najprawdopodobniej służyła jako wypełniacz żelu. W konsekwencji może to skutkować wzmocnieniem struktury badanego produktu. Kolejną badaną cechą był kąt fazowy opisujący zależność cech między lepkimi i elastycznymi składnikami badanego produktu (Murata, 2012). Kiedy G′ reprezentuje wyższe wartości niż G″, oznacza to, że tg (δ) <1. Takie wartości wskazują, że mierzone próbki mają właściwości bardziej sprężyste niż lepkie. Wartości tg (δ) dla każdego z badanych produktów były mniejsze niż 1, co oznacza, że otrzymane sosy mają właściwości sprężyste. Lopez i in. (2001) zaobserwowali, że bezwodny tłuszcz mleczny topi się w temperaturze 40–41°C (Lopez i in., 2001). Stopiony tłuszcz może częściowo wypełniać przestrzenie międzybiałkowe w produkcie opartym na WPC80, a pozostała jego część zwiększa objętość próbki sosu serowego, powodując wzrost wartości modułów G′ i G″ i jednocześnie zmniejszenie wartości tg (δ). Dodatkowo temperatura stosowana podczas procesu homogenizacji (80ºC) może być związana z procesem tworzenia się żelu. Gdy zawartość laktozy w koncentratach i izolatach jest niewielka, ich temperatura żelowania zmienia się podczas denaturacji białek serwatkowych (Rich & Foegeding, 2000).

Granica płynięcia (yield stress) determinuje podstawowe cechy sosów serowych. Właściwości reologiczne materiałów ciekłych i stałych, opisujące wytrzymałość struktury materiału, definiuje się jako minimalne naprężenie niezbędne do spowodowania przepływu badanego materiału (Alves, 2017). W Tabeli 5 przedstawiono wartości granicy płynięcia (Pa). W przypadku, gdy produkt nie może wytrzymać nacisku - ulega deformacji i zaczyna płynąć. W większości próbek wartość granicy płynięcia zwiększała się wraz z ilością dodawanego błonnika. Natomiast w sosach z OCO/AMF + AF zaobserwowano zmniejszenie tego parametru wraz z większą ilością dodanego błonnika. W sosach z AMF + BF wartości granicy płynięcia zwiększyły się w produkcie z dodatkiem 1–3% błonnika i były znacznie niższe w przypadku 4% BF (**publikacja IV**). Wartości opisywanej cechy były znacznie niższe w próbkach sosów na bazie oleju rzepakowego w porównaniu z pozostałymi produktami.

Gęstość poszczególnych olejów i tłuszczu zmniejsza się, gdy zmieniają swoją postać ze stałej w płynną. Gęstość bezwodnego tłuszczu mlecznego w temperaturze 15ºC wynosi 0,935–0,943, a oleju kokosowego 0,919–0,937 (Bockisch, 1998). Może to wskazywać, że olej/tłuszcz stosowany w badaniach miał wpływ na badane produkty, podobnie jak zastosowane błonniki. Gęstość sosów z dodatkiem bezwodnego tłuszczu mlecznego zwiększała się w produktach z błonnikami: bambusowym, cytrusowym oraz ziemniaczanym ($P < 0,05$) oraz w sosach z dodatkiem oleju kokosowego oraz błonników: cytrusowego i ziemniaczanego (Tabela 6) (**publikacja IV**). W przypadku produktu z olejem kokosowym, zwiększenie gęstości miało miejsce w próbkach z błonnikiem cytrusowym.

Aktywność wody (a_w) badanych sosów serowych wahała się w przedziale między 0,971 – 0,998 (Tabela 6). Uzyskane wartości pomiarów produktów w większości przypadków nie wykazywały statystycznie istotnych różnić między sobą ($P > 0.05$). Jedynie w przypadku 4% BF+AMF (0.971) odnotowano wartość niższą w porównaniu do innych sosów. W sosach z dodatkiem oleju kokosowego oraz 2, 3, 4% BF aktywność wody wahała się w przedziale 0,980-0,981, podobnie w przypadku produktu z 4% AF.

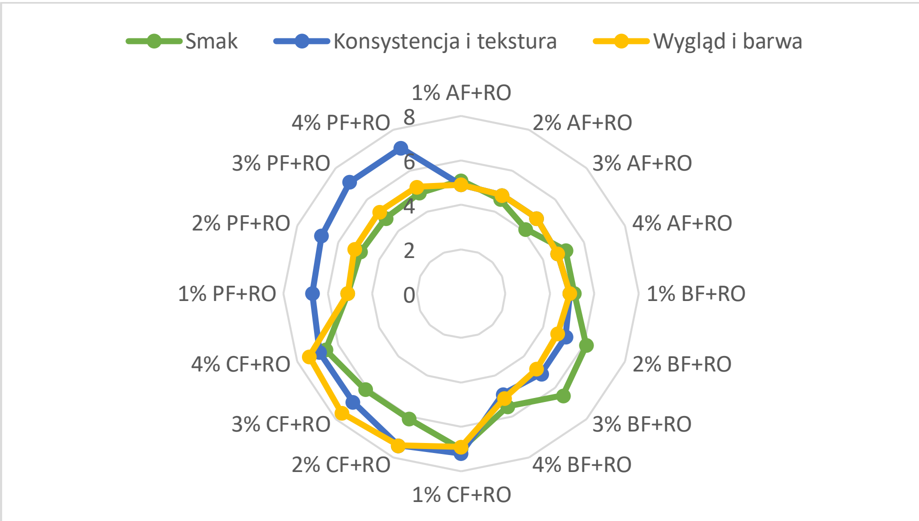
Table 6. Wpływ różnej zawartości błonników (akacjowego – AF, bambusowego – BF, cytrusowego – CF oraz ziemniaczanego – PF) na gęstość i aktywność wody sosów otrzymanych na bazie kazeiny kwasowej, WPC80 i oraz olejów: rzepakowego, kokosowego lub bezwodnego tłuszczu mlecznego.

Tłuszcz/ olej	**Błonnik**	**Gęstość (g/ml)**				**Aktywność wody**			
		Zawartość błonnika (%)				Zawartość błonnika (%)			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Olej kokosowy (OCO)	AF	1,071^{f-i} ±0,001	1,067^{e-h} ±0,002	1,65^{d-g} ±0,004	1,061^{c-f} ±0,001	0,998^{b} ±0,001	0,989^{b} ±0,002	0,992^{b} ±0,003	0,979^{ab} ±0,001
	BF	1,046^{a} ±0,001	1,047^{ab} ±0,004	1,058^{c-e} ±0,002	1,054^{a-c} ±0,003	0,990^{b} ±0,001	0,980^{ab} ±0,001	0,981^{ab} ±0,002	0,981^{ab} ±0,001
	CF	1,064^{d-g} ±0,002	1,068^{e-h} ±0,002	1,068^{e-h} ±0,00	1,070^{e-h} ±1,002	0,985^{b} ±0,004	0,988^{b} ±0,003	0,988^{b} ±0,001	0,990^{b} ±0,001
	PF	1,072^{g-j} ±0,002	1,071^{f-i} ±0,001	1,081^{j-m} ±0,007	1,091^{mn} ±0,007	0,984^{b} ±0,001	0,985^{b} ±0,001	0,980^{b} ±0,001	0,990^{b} ±0,001
Tłuszcz mleczny (AMF)	AF	1,045^{a} ±0,004	1,060^{c-e} ±0,003	1,044^{a} ±0,002	1,078^{i-l} ±0,004	0,988^{b} ±0,001	0,985^{b} ±0,003	0,986^{b} ±0,001	0,984^{b} ±0,001
	BF	1,068^{e-h} ±0,001	1,068^{e-h} ±0,001	1,076^{h-k} ±0,005	1,086^{k-m} ±0,005	0,988^{b} ±0,001	0,984^{b} ±0.001	0,985^{b} ±0,001	0,971^{a} ±0,005
	CF	1,045^{a} ±0,005	1,084^{k-m} ±0,005	1,080^{i-l} ±0,003	1,090^{mn} ±0,006	0,996^{b} ±0,004	0,990^{b} ±0,003	0,990^{b} ±0,001	0,980^{ab} ±0,001
	PF	1,056^{b-d} ±0,002	1,079^{i-l} ±0,001	1,088^{l-n} ±0,001	1,098^{n} ±0,001	0,980^{ab} ±0,001	0,990^{b} ±0,001	0,990^{b} ±0,001	0,990^{b} ±0,003
Olej rzepakowy (RO)	AF	1,065^{d-g} ±0,004	1,054^{a-c} ±0,003	1,047^{ab} ±0,002	1,046^{a} ±0,023	0,995^{b} ±0,003	0,996^{b} ±0,002	0,998^{b} ±0,001	0,997^{b} ±0,001
	BF	1,071^{f-i} ±0,005	1,078^{i-l} ±0,004	1,071^{f-i} ±0,003	1,046^{a} ±0,004	0,989^{b} ±0,002	0,994^{b} ±0,001	0,994^{b} ±0,001	0,998^{b} ±0,001
	CF	1,065^{d-g} ±0,003	1,077^{i-l} ±0,009	1,089^{l-n} ±0,005	1,093^{mn} ±0,006	0,998^{b} ±0,001	0,994^{b} ±0,002	0,995^{b} ±0,001	0,995^{b} ±0,001
	BF	1,067^{e-h} ±0,002	1,065^{d-g} ±0,004	1,078^{i-l} ±0,004	1,071^{f-i} ±0,003	0,992^{b} ±0,003	0,989^{b} ±0,002	0,994^{b} ±0,001	0,993^{b} ±0,001

Objaśnienie: Różne litery (a-u) w tej samej kolumnie wskazują na istotne różnice przy P <0,05.

6.3.3. Ocena organoleptyczna

Na różnych etapach pracy przeprowadzono ocenę organoleptyczną otrzymanych produktów. Wstępna analiza została wykonana na Wydziale Nauk o Żywności i Biotechnologii Uniwersytetu Przyrodniczego w Lublinie według schematu Clarka, Costello, Drake & Bodyfelt (Clark i in., 2009). Otrzymany produkt na bazie błonników dietetycznych (akacjowego, bambusowego, cytrusowego i ziemniaczanego) oraz oleju rzepakowego oceniało 10 nieprzeszkolonych panelistów. Oceniano następujące cechy sosu: smak (1–10 pkt), konsystencja i tekstura (1–5 pkt) oraz wygląd i barwa (1–5 pkt). Wyniki zostały opisane na wykresie 4 (**publikacji III).**

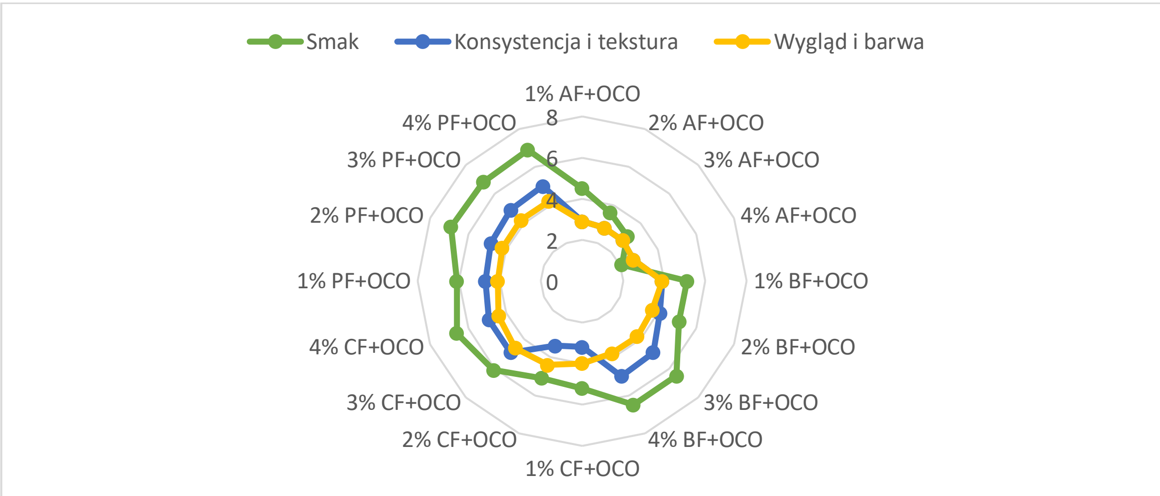


Wykres 4. Wpływ zawartości różnych rodzajów błonnika dietetycznego (błonnik akacjowy – AF, błonnik bambusowy – BF, błonnik cytrusowy – CF, błonnik ziemniaczany- PF) na ocenę organoleptyczną sosów serowych otrzymanych na bazie kazeiny kwasowej, WPC80, z dodatkiem oleju rzepakowego.

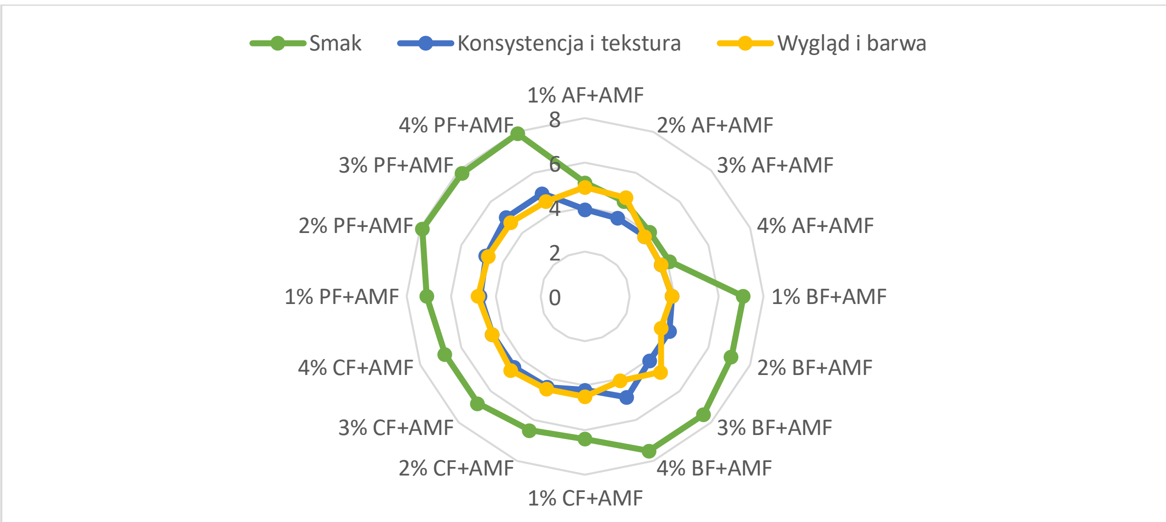
Nie wszystkie badane sosy zostały dobrze przyjęte przez panelistów, a różnice między produktami były zauważalne. Sosy serowe z dodatkiem błonnika akacjowego (AF) uzyskały najniższe oceny spośród wszystkich badanych próbek dla wszystkich badanych cech (smak: 4,1–5,1; konsystencja i tekstura: 4,7–4,9; wygląd i barwa: 4,7–4,9). Wiązało się to z ich półpłynną konsystencją. Spośród prób z błonnikiem akacjowym najlepiej ocenione zostały produkty z dodatkiem 1%. Grupa sosów z BF charakteryzowała się najwyższymi ocenami z dodatkiem 2 i 3%. Sos z BF został opisany jako zbyt jasny, wręcz biały. Błonnik bambusowy wykorzystany w badaniu był biały, co mogło spowodować, że produkt końcowy miał ten sam ton. Spośród wszystkich przebadanych sosów, produkty z dodatkiem CF uzyskały najwyższe oceny w każdej opisanej kategorii. Sos z dodatkiem PF, mimo dobrej konsystencji, nie został dobrze oceniony pod względem wyglądu. Ponadto jego kolor również został źle przyjęty przez panelistów. Ze wszystkich ocenionych próbek najwyższy wynik opisujący kolor uzyskał sos z dodatkiem CF. Produkty z tym dodatkiem zostały opisane jako najbliższy odpowiednik sosów serowym ze wszystkich przebadanych próbek. Najwyższe oceny ogólnej wartości oceny organoleptycznej uzyskał sos serowy z BF i CF. Pod względem smaku niższą notą charakteryzowały się sosy serowe z AF i PF (**publikacja III**).

Dodatkowo została przeprowadzona ocena organoleptyczna sosów na bazie oleju kokosowego oraz bezwodnego tłuszczu mlecznego z błonnikami dietetycznymi. Otrzymane wyniki nie zostały jeszcze opublikowane i będą stanowić część danych podczas opracowywania przyszłych artykułów.

4a)



4b)



Wykresy 4a i 4b Wpływ zawartości różnych rodzajów błonnika dietetycznego (błonnik akacjowy – AF, błonnik bambusowy – BF, błonnik cytrusowy – CF, błonnik ziemniaczany- PF) na ocenę organoleptyczną sosów serowych otrzymanych na bazie kazeiny kwasowej, WPC80, z dodatkiem oleju koksowego lub bezwodnego tłuszczu mlecznego.

Na wykresach 4a i 4b przedstawiono wyniki dla poszczególnych serii produktów. Analizy zostały przeprowadzone zgodnie z wcześniej przyjętym schematem, który został wykorzystany w publikacji III. Na podstawie uzyskanych wyników można stwierdzić, że najwyższe oceny podczas analizy uzyskały produkty z dodatkiem bezwodnego tłuszczu mlecznego. Najwyższe oceny odnośnie smaku i konsystencji uzyskały produkty z dodatkiem błonnika bambusowego oraz ziemniaczanego. W obu przypadkach wszystkie testowane sosy z różnym dodatkiem wspominanych błonników uzyskały ocenę wyższą niż 7. Produkty z dodatkiem oleju kokosowego zostały niżej ocenione, zwłaszcza w przypadku próbek z błonnikiem akacjowym (smak: 2,1-4,5; konsystencja i tekstura: 2,7-2,9; wygląd i barwa: 2,7-2,9). Zostały one opisane jako zbyt płynne, o nieprzyjemnym posmaku i kremowo-białym kolorem, który odbiega od typowego koloru sosów serowych. Negatywne opinie odnośnie smaku tych sosów mogą być spowodowane zbyt intensywnym aromatem oleju kokosowego. Produkty z dodatkiem AF zostały określone jako zbyt jasne, wręcz białe. Opis podany przez panelistów mógł być powiązany z kolorem błonnika użytego do przygotowania sosów. Błonniki - akacjowy oraz bambusowy są białe, a produkt końcowy miał tę samą barwę. W badaniach dotyczących jogurtu z błonnikiem bambusowym otrzymano podobne wyniki (Seçkin & Baladura, 2012).

Spośród wszystkich przebadanych sosów, produkty z dodatkiem PF uzyskały najwyższe oceny. Posiadały one dobrą konsystencje i aromat. Błonnik ziemniaczany, ze względu na swój wygląd i barwę jest także chętnie dodawany do mięsa (Mehta i in., 2015) lub chleba (Kaack i in., 2006). Również ze wszystkich przebadanych próbek najwyższy wynik opisujący barwę uzyskały sosy z dodatkiem bezwodnego tłuszczu mlecznego. Według panelistów barwa tych produktów była najbliższa sosom serowym, biorąc pod uwagę wszystkie przebadane próbki.

7. Stwierdzenia i Wnioski

1. Na podstawie przeprowadzonych badań można stwierdzić, że zastosowanie koncentratu białek serwatkowych (WPC80), błonników dietetycznych oraz różnych źródeł olejów i tłuszczu miało wpływ na właściwości fizykochemiczne i cechy organoleptyczne sosów serowych otrzymanych na bazie kazeiny kwasowej.
2. Wyniki uzyskane w przeprowadzonych badaniach mogą sugerować, że sosy serowe z najmniejszą zawartością (2%) koncentratu białek serwatkowych (WPC80) nie spełnią oczekiwanych wymagań, ze względu na zbyt płynną strukturę i niską lepkość, nie przypominającą sosów serowych.
3. Sosy z dodatkiem bezwodnego tłuszczu mlecznego znacznie bardziej przypominały barwą tradycyjne sosy serowe, co może wpływać na wybór produktu przez konsumentów.
4. Każdy testowany produkt wykazywał właściwości słabego żelu (G′>G″), a wartości modułów: zachowawczego (G′) i stratności (G″) sosów serowych były skorelowane z wartościami twardości otrzymanych produktów.
5. Gęstość sosów serowych bez dodatku błonnika otrzymanych na bazie oleju kokosowego czy rzepakowego była większa niż próbek otrzymanych na bazie bezwodnego tłuszczu mlecznego, natomiast aktywność wody nie zmieniła się wraz ze wzrostem zawartości WPC80.
6. Dodatek błonników wpłynął na teksturę sosów serowych. Błonnik cytrusowy zwiększył twardość produktu końcowego. Jednocześnie zmniejszyła się lepkość pozorna sosu z dodatkiem ww. błonnika.
7. Obserwowana poprawa właściwości teksturalnych przejawiająca się mniejszą twardością w większości próbek sugeruje, że użyte w badaniu błonniki mogą być potencjalnie zastosowane jako dodatek do sosów serowych, otrzymywanych na bazie kazeiny kwasowej i koncentratu białek serwatkowych (WPC80). Najniższe wartości twardości zanotowano w próbkach na bazie oleju rzepakowego.
8. Paneliści najwyżej ocenili produkty z dodatkiem błonnika ziemniaczanego na bazie bezwodnego tłuszczu mlecznego.
9. W każdej z przebadanych grup najniższe oceny otrzymały produkty z dodatkiem błonnika akacjowego. Zostały określone jako zbyt płynne i posiadające barwę, która odbiega od typowego sosu serowego.
10. Najniżej pod względem smaku i aromatu zostały ocenione sosy serowe z dodatkiem oleju kokosowego.

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REVIEW ARTICLE

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Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects

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Abstract

During recent years, companies producing dairy products have observed an increase in the consumption of cheese sauces. The purpose of this review is to provide a critical overview of the most important properties of cheese sauces: ingredients, additives, processes, different methods used for their manufacturing, microbiological and sensory aspects, all of which is interesting both for the food industry and consumers. Because it is expected that the consumption of such products will increase, it is worth getting acquainted with current production processes for cheese sauces and the possibilities of modifying them in terms of consumer preferences, trends, and health-promoting properties.

Practical applications

This review shows how the interactions among ingredients, the usage of hydrocolloids, emulsifying salts, and other functional components, and processing conditions can be handled to obtain cheese sauces with targeted characteristics. Moreover, advancements in recent years have enabled cheesemakers to increase the quality of cheese sauces in terms of nutritional value. These aspects could be interesting for the food industry (product development technologists), scientists, and consumers.

1 | INTRODUCTION

Over the past years, cheese and products based on it have been growing in commercial importance. For example, in the United States, consumption of cheese per capita in 1980 was about 2.3 kg, while in 2015 it was close to 15.8 kg (United States Department of Agriculture Economic Research Service, 2019). This increase was influenced by many factors, primarily, years ago, cheese producers did not understand processes related to the manufacturing of cheese and used routine methods in its production that were not always the best and did not produce the best quality products (Johnson, 2017).

Cheeses may differ from one another in terms of their color, aroma, texture, taste, and firmness, which can generally be attributed to production technology, milk source, moisture content, and length of aging, in addition to the presence of specific molds, yeasts, and bacteria (Santiago-López et al., 2018).

Trends in the food market are determined by the expectations and requirements of consumers and producers. In recent years, an increase in the consumption of cheese sauces and dips has been observed due to the fact that more and more people are changing their food preferences and it is, therefore, anticipated that there will be intensive development in the cheese sauce market. In a recent global report on the cheese sauce market, it is estimated that it will grow by several million dollars through the forecasted period of 2017 until 2022. This trend is expected to rise in the following years; therefore, the number of concepts and solutions dedicated to the production of sauces, especially cheese, is constantly growing (Orbis Research, 2017).

Due to the versatility of using cheese sauce, for example, for topping, dipping, or grilling, and many other applications such as coatings, manufacturers are trying to outdo the creation of new formulas and production technologies. This article presents collection of complex information related to cheese sauces and review of current research and experiments regarding this topic. Dairy industry is one of the most engaged in creation of new products with different functionalities. To support food producers, introducing new and innovative products to consumers, ingredients, manufacturers offer a range of dairy ingredients to improve texture, flavor, reduce sodium content, or increase nutritional attractiveness (Nachay, 2015). For example, novel processed cheese sauces with essential oils (Shalaby, Mohamed, & Bayoumi, 2017) or cheese sauces with *Lactobacillus salivarius* strain Ls-33, acting preventively against myocardial infarction (Stenman, Lahtinen, & Konhilas, 2018).

2 | GENERAL DEFINITION

A sauce is defined as "usually liquid or semiliquid, eaten as a gravy or relish accompanying food" (Dictionary, 2019). Sauce performs different functions, for example, it adds flavor, moistness, texture, or body to meals. Cheeses or processed cheeses are mainly used as basic ingredients in cheese sauce, recognized as a thickening type of sauce (Salek et al., 2019). The difference between a dip and a sauce is small but quite significant. Due to their light consistency, sauces are prepared to emphasize the taste of the served dish. They can be served either warm or cold and this is the fundamental difference which distinguishes a sauce from a dip. The consistency of a dip is much thicker and serves primarily to break the taste of the food. Moreover, dip is usually served in a separate container and is cold (International Food Information Service [IFIS], 2009).

3 | LEGAL DEFINITION

In the "Reference Amounts Customarily Consumed: List of Products for Each Product Category: Guidance for Industry", cheese sauce does not have its own category as a product (Food and Drug Administration [FDA], 2018). Because of this, it belongs to the group of products for which there are no standards or legal definitions and, as a result, producers can use a variety of base ingredients and additives while preparing them. However, it is important that each component has the ability to dissolve in water. Guaranteeing this feature will allow obtaining of practically every possible type of cheese sauce (Brandt, 2001).

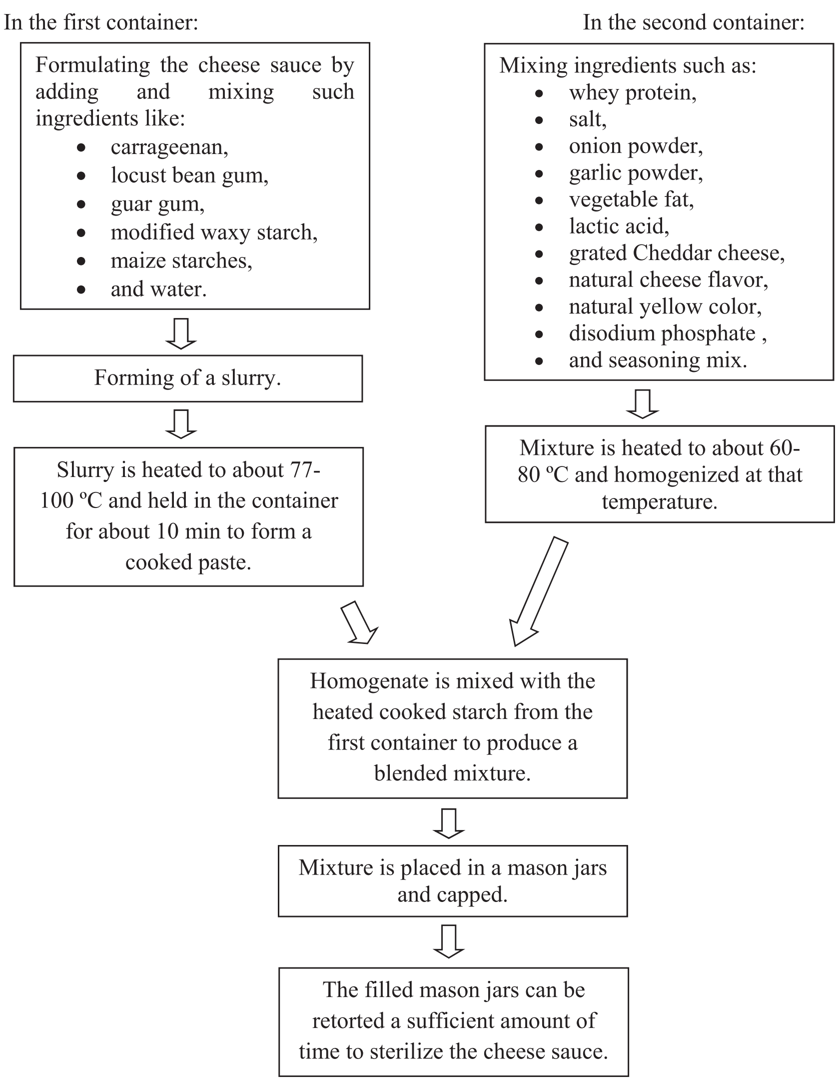

FIGURE 1 Block diagram of the cheese sauce production based on patent from 1986 No. 4,568,555 (Spanier, 1986)

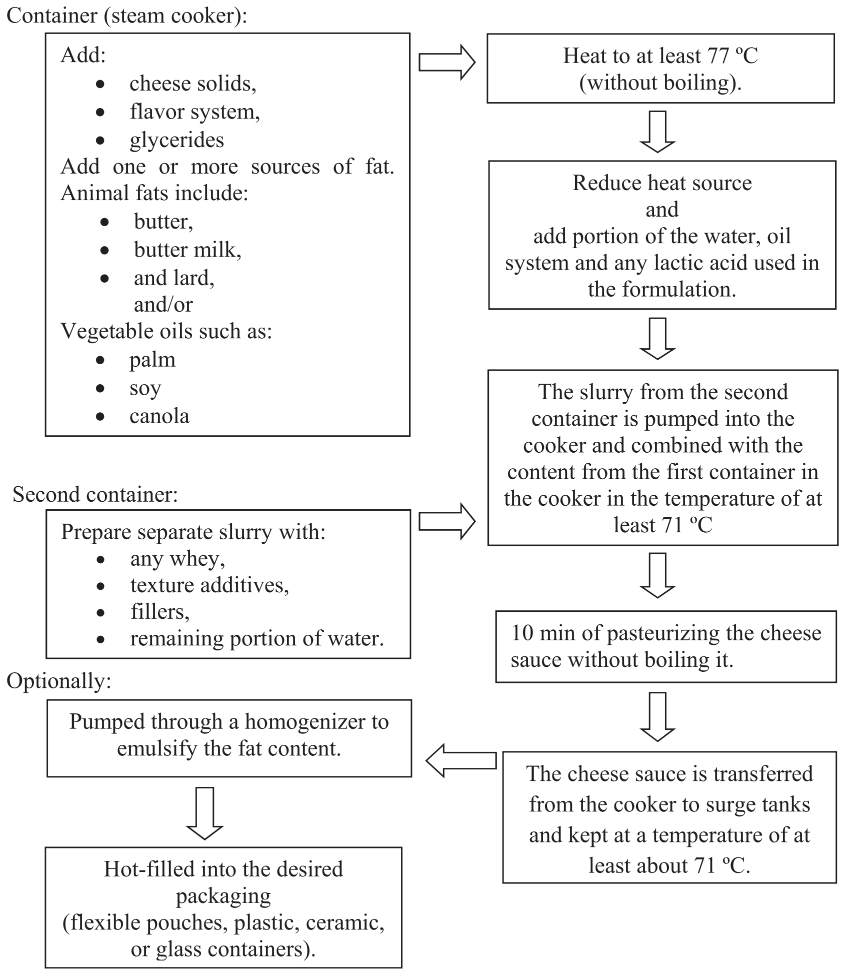

FIGURE 2 Block diagram of the cheese sauce production based on patent from 2011 No. 2011/0045145 (Gamay et al., 2011)

4 | CHEESE SAUCE PROCESSING

There is no single specific block diagram describing the production process for a cheese sauce. Due to the multitude of ingredients from which it can be made, several patents have been registered in which methods of producing the sauce, along with exact proportions, have been presented. One of the first patents of the cheese sauce production was registered in 1986 and its formation can be illustrated in the block diagram (Spanier, 1986) (Figure 1):

Another modified block diagram was proposed in 2011 by Gamay, Gammons, and Smith (2011). To make a low-cost, shelf-stable cheese sauce, the authors proposed another method (Figure 2).

Figures 1 and 2 show schemes for cheese sauce production. The first one is based on a mixture of gums and starches which are very important to achieve a good mouthfeel. Gums are texture enhancers and help to control the viscosity of the cheese sauce, they can be mixed into the formulation and examples are sodium alginate, guar gum, and xanthan gum (Gamay et al., 2011). The cheese used in making the cheese sauce also affects its flavor. Cheeses that can be used for cheese sauce production are Cheddar cheese, enzyme-modified cheese (EMC), granular cheeses, Parmesan or Provolone (Krumhar, Phillips, Moffitt, & Damiano, 1998). Younger cheeses will provide a milder taste compared to the older ones which will add a more flavorful taste to the cheese sauce. Sometimes, producers blend older cheeses with younger varieties to get a particular desired flavor contribution (Gamay et al., 2011). The flavor and texture of the final product are controlled by proteins and salt levels, for example, phosphate salts or sodium chloride. Whey protein gives the cheese sauce a proper structure and also an appropriate mouthfeel. In cheese sauce production, different types of starches are used being natural or unmodified food-grade starches, for example, tapioca starch, potato starch, and rice starch (Hine, 1994). To create an emulsion with water, as seen in Figures 1 and 2, the authors suggested using oils. In the first method of production (Figure 1), it is proposed to use vegetable fat—coconut, corn, or soybean oil, as they are better than animal oils which are more prone to rancidity (Spanier, 1986). For the other method (Figure 2), the authors used sustainable quantities of both animal fat and vegetable oils; however, the addition of oil can cause a negative impact on the texture of cheese sauce. Figure 2 shows that reducing the impact of oils on the texture is possible after adding suitable fillers such as corn syrup solids or maltodextrins. Water activity on cheese sauces depends on the content of free water occurring in the production system. High water activity in a product can cause fungus, mold, and bacterial proliferation (Gamay & Schumacher, 1999). In the above-mentioned methods, water is supplied not only by the specific added amount of water but also from steam used during the pasteurization process (Gamay et al., 2011).

The pH value of the cheese sauce has an influence on the texture, desirable taste and also affects balanced bacterial and pathogen growth. From the 1980s, a lot of research has been done to determine the optimal conditions for preparation of cheese products such as cheese sauces or spreads and products with cheese solids greater than 20% weight. Tests carried out by Tanaka et al. (1986) demonstrated that the optimal pH for cheese sauces is pH <5.7 and this can be manipulated by the addition of phosphate salts, sodium chloride, or sorbic acid. For example, linear chains of sodium hexametaphosphate peptize proteins and sequester minerals. Cheese pH affects protein configuration. Specific pH values are corresponding with their isoelectric points, which reduce their interactions with other phases. Controlling this parameter can be done through selecting appropriate cheese and other ingredients that are used in production of cheese sauces (Burrington, 2003).

There are no great differences of specific pH values in cheese sauces with different protein sources. Saad, EL-Mahdi, Awad, and Hassan (2016) proved that pH values ranged in studied cheese bases between 5.85 and 5.78. The differences may occur due to structure and origin of tested products. El-Mahdi, Saad, Hassan, and Avard (2014) used similar pH ranges. They tested starch and other stabilizers as thickening agents in manufacture of processed cheese sauces on the basis of Ras cheese. Authors also reported that after 3-month storage at room temperature and in 5°C, the pH values of processed cheese sauces decreased slowly in all samples until the end of storage period. There were no significant differences in final pH between samples stored in room temperature and in 5°C (5.62 and 5.65, respectively).

Selection of suitable phosphate affects both melting and texture of cheese and cheese sauces. Also, phosphate salts solubilize proteins from cheese and dairy solids, which can act as an emulsifier. Positive charges on casein proteins interact with anionic phosphates which can cause unfolding of the proteins so they behave as emulsifiers (Pelofske, 2016). To control pH of cheese, producers can use appropriate emulsifiers such as phosphates, citrates, aluminum phosphates, or pyrophosphates (Gamay & Schumacher, 1999). In 2019 researchers tested different types of emulsifying salts (ESs) that can be used in preparation of processed cheese sauces: disodium hydrogen phosphate, tetrasodium disphosphate, pentasodium triphosphate, sodium salt of polyphosphate n ~ 20 and trisodium citrate (Salek et al., 2019).

The flavor system used in cheese sauce formulation should be chosen in such a way as to most closely imitate a particular flavor profile while having minimal impact on the texture. Sorbic acid is often added as a yeast or mold inhibitor and can extend the shelf life of the final product (Gamay et al., 2011). Lactic acid is added to avoid the consequences associated with excessive amounts of phosphate salts being used in the production of cheese sauce. Finally, a certified food colorant can be added to provide the desirable yellow color (Spanier, 1986).

5 | OVERVIEW OF INGREDIENTS USED TO PRODUCE CHEESE SAUCE

5.1 | Cheese

Cheese, the basic component of cheese sauce, does not contain vitamin C or fiber; hence, it is a good idea to combine it with vegetables or fruit (Scott, 1998). The exact quantity of nutrients in cheese sauce depends on the type and quality of cheese, which is a source of many nutrients such as proteins, fatty acids, vitamins, and minerals. Cheese contains vitamin A, group B vitamins (B2, B3, B9, B12), and vitamin D as well as calcium, magnesium, potassium, sodium, and phosphorus. The nutrient content varies depending on the type of cheese (Fox, McSweeney, Cogan, & Guinee, 2017; Kwak, Ganesan, & Hong, 2011).

Natural cheese provides a solid base in a cheese sauce formula, into which other ingredients can be incorporated. In general, cheese sauce contains from about 20 to 50% (by weight) of cheese solids. Products with more than 51% of cheese solids are characterized as "spreads" (Gamay et al., 2011). The literature also describes sauce recipes that not require any natural cheese, only addition of cheese flavor (Kasik & Peterson, 1977). The main classes of cheese used for the production of sauces are Masslander, Cheddar, Emmentaler, Gorgonzola, and Roquefort, depending on various types of cheese that can be used in production, for example, cheese with high or low fat content, different chemical composition, or bacteria used in cheese aging (Gamay et al., 2011). Natural cheese affects not only the flavor of the sauce but also its body, texture, and different mouthfeel of the final product. It adds structure and improves adherence to the dish it is served with. When the amount of cheese is reduced in sauces, the viscosity and texture are worsened (Banes, Helm, & Taylor, 2014). Due to the action of bacteria starter culture and fungi during cheese ripening, proteins and fats are divided into simpler compounds such as amino acids and free fatty acids. At the same time, their solubility increases which makes the taste of the cheese stronger. Cheese aged from 2 to 5 months will be milder than older cheese that has been ripening for more than 5 months. The taste of aging cheese will be sharper. Also, aged cheese will have a reduced ability to emulsify. Using an aged cheese in production will result in a shorter and more curdy texture of cheese sauce. Sometimes, producers mix younger and older cheeses to get the desired taste of cheese sauces (Gamay et al., 2011).

5.2 | Cheese powder

Dehydrated cheese (e.g., cheese powder) is often used as a substitute for natural cheese. It provides the best combination of flavor and texture in food products such as sauces and is produced from cheeses such as Camembert or Cheddar (da Silva, Ahrné, Larsen, Hougaard, & Ipsen, 2018). The amount of cheese powder used in production is typically between 5 and 10%, depending on the desired intensity of flavor. The amount of this ingredient also depends on the levels and types of other flavorings. Using described amounts of cheese powder does not have much impact on the rheological properties (Fox et al., 2017). Physical properties of dehydrated cheese, such as color and density, are very important parameters of quality; a wrong color indicates defects during processing (Koca, Erbay, & Kaymak-Ertekin, 2015). Structural and morphological features of cheese powder, for example, free fats, affect the oxidation during storage. On the other hand, properties such as thermal effects and rehydration can be affected by different factors such as cheese raw ingredients (Fox, McSweeney, Cogan, & Guinee, 2004). The preparation of cheese powders is based on mixture consisting of natural cheese, water, different additives, ESs, starch, flavors, and antioxidants. To get molten slurry, the blend is heated to 75–85°C, homogenized, and spray dried (Fox et al., 2004).

According to Lewin (1996) and Mortensen (1999), cheese powders can be combined with different spices, such as cumin, chili, onion, or garlic.

5.3 | Milk powder

Milk powder is characterized by oxidative stability. Due to the removal of water during production, it can also minimize microbial growth in products. It can, therefore, be applied in the preparation of soups and desserts (Hu & Jacobsen, 2016) but also in cheese sauces (Early, 2008).

Powdered milk is included in the group of dried dairy products where the fat content in their composition never exceeds 40% (Table 1). Dried dairy products contain ingredients such as milk powders and protein powders such as whey protein isolate and whey protein concentrate (WPC) (Hu & Jacobsen, 2016).

5.4 | Modified whey proteins

Modified whey protein (MWP) is another food ingredient used in cheese sauce production to replace cheese in sauces. It functions like fat globules and as a result, the amount of cheese used in production can be reduced. It also gives texture improvements but should not be confused with starches and hydrocolloids which are true viscosifying ingredients and cannot be completely eliminated during sauce production. Their addition allows the cost of the MWP to be reduced compared to real cheese which is also an advantage (Banes et al., 2014).

TABLE 1 The moisture levels of milk powders based on Hu and Jacobsen (2016)

Name	Fat by weight
NFDM—Nonfat dry milk	Pasteurized skim milk that containing:
SMP—Skim milk powder	<1.5% fat by weight ≥34% protein by weight
WMP—Whole milk powder	Pasteurized whole milk that containing: 26–40% fat by weight
BMP—Buttermilk powder	From the buttermilk that containing: More than 4.5% milk fat

5.5 | Stabilizer

Stabilizers are food additives that play a role in maintaining physicochemical properties such as consistency or composition in food products. They prevent and delay the occurrence of adverse chemical and physical changes. As inhibitors of chemical reactions, they can also weaken the influence of biological or thermal factors. In the food industry, they provide invaluable functional properties such as the ability to bind the suspension in solution, preventing decomposition of dyes and emulsion sedimentation (Food additives, 2019).

In cheese sauce production, stabilizers such as sodium caseinate or milk protein (e.g., whey), and gums—guar gum, locust bean gum, xanthan gum, carrageenan, or alginates are used (Visee, 2001).

El-Mahdi et al. (2014) reported that the addition of corn starch and guar gum or sodium alginate as stabilizers produces processed cheese sauces as an end product with excellent flow-ability and mouthfeel. Hassan, Award, El-Mahdi, and Saad (2015) tested impact on the product of different substances: xanthan, κ-carrageenan, pectin, guar gum, and sodium alginate. Researchers discovered that all stabilizers improved properties of cheese sauce. They affected the flow behavior in all final products. Cheese sauces with addition of tested compounds were highly acceptable compared to the control sauce. Moreover, products with guar gum and sodium alginate were characterized by highest freshness during storage (Hassan et al., 2015).

5.6 | Water

The process of preparing a cheese sauce from U.S. Patent No. 5,059,433 describes that water content is 70–85% of the final product and cheese is 5–15% (Lee, Hoyda, & Merritt, 1991).

Water is a solvent for many polar substances and process factors in the food industry. It is essential to remove the iron, copper, and magnesium ions contained in it because they are the main cause of oxidation processes, that is, fat rancidity. In the dairy industry, rancid fats can additionally cause stains on butter and cheese and emit an unfavorable, bitter aftertaste (Boguniewicz-Zablocka, Klosok-Bazan, & Naddeo, 2019; Sheldrake, 2003).

In cheese sauce production, water addition completes the taste of the product and gives it a liquid and creamy consistency. Not only sauces but also soups and dressings are characterized by the continuous water phase and its behavior with oil affects the texture of these products (Sheldrake, 2003). Moreover, proteins, for example, whey proteins, can interact with water and form water suspensions. This property can indicate whether the whey protein has denatured. Interaction of proteins with water can cause thickening or increase viscosity (Nastaj et al., 2019). Water and whey protein interaction increases above 65°C and from 85°C, whey proteins denature and aggregate. This process causes further increases in viscosity (Kilara, 2004).

5.7 | Roux

Roux is a specific base that can be prepared by mixing and heating fats with flour. It is used for thickening of sauces. Products manufactured from this base by addition of liquid (e.g., milk or stocks) and heating, to thicken the liquid, are known as "roux sauces" (International Food Information Service [IFIS], 2009). The roux can be used as another base for the cheese sauce. It mainly consists of animal fats (butter) and vegetable oils (palm oil), wheat flour or tapioca flour, corn starch, and additives such as herbs and spices (Visee, 2001). There are two main types of roux used in cheese sauces preparation. Depending on which will be used, they give the final product quite different characteristics. White roux is prepared at a temperature between 120 and 130°C and does not change color, having pleasant milk-like flavor. In turn, mixture prepared in temperature from 160 to 180°C has brown color and because of that fact, it is called a "brown roux." Differences between them cause that they are used to prepare various type of sauces (Kato, 2003). Moreover, temperature is the main factor that has impact on aroma of the final product. With regard to the flavor of white roux, it was characterized by slight roasted odor of the aldehydes and carboxylic acids, while the flavor of brown roux has been strongly influenced by the compounds such as furans and cyclic ketoenols (Kato, 2003).

The melting point of individual fats should be between 10 and 40°C. Preparation of the roux begins with the mixing of individual ingredients, simultaneously heated to a temperature of 70 to 110°C for no more than 10 min. Such a created base can be directly used for the production of cheese sauces, or chilled and used at a later time.

According to Visee (2001) cheese sauces can be obtained on two bases. First one uses fresh cheese and the second one, cheese with the addition of roux. Both of them include fresh cheese or a mixture of different cheeses, ESs—performing the functions of an emulsifier, water, potassium sorbate, and sodium caseinate. All components for cheese sauce are mixed under direct steam heating at a temperature of 85–110°C, until a homogeneous consistency is obtained. The mixture created in this way is used in the further stages of sauces production. Prepared roux is first cooled and then rubbed. The next stage is based on the mutual mixing of two bases. Both are placed into specialized vessels, where they are mixed together. The mixture has to be kept in temperature between 60 and 70°C without additional heating. It is also important to maintain proper proportions between both bases; hence, the most commonly used weight ratio is from 95:5 to 5:95 or from 90:10 to 50:50 (Visee, 2001). The resulting mixture is placed in special container and hardened for 24 to 48 hr in a temperature from 0 to 2°C. After a predetermined time, the friction process is carried out at about 8°C and the mixture is placed in special bags. At the end with a slight heating, the mixture is enriched with water, resulting in a sauce without lumps and with a homogenous, desirable consistency (Gamay et al., 2011; Visee, 2001).

5.8 | Hydrocolloids

Hydrocolloids are macromolecular substances that can dissolve in both cold and warm water, while at the same time forming dispersion systems and viscous solutions. In the food industry, they are used as functional additives that affect the specificity of food. Their key function is to shape the product structure and give it appropriate stability (Dłużewska & Krygier, 2007). They are gelling, thickening, and emulsifying substances that inhibit the formation of sugar and ice crystals and are called clarifying substances. In the finished product, they are responsible for shaping physical properties, referred to as the texturing function.

The particular hydrocolloids most often used for cheese sauce production are alginates, xanthan gum, carrageenan, and guar gum, although they do not have exactly the same properties, for example, carrageenan provides less acid-tolerance than xanthan gum (Hassan et al., 2015). Carrageenan used in the correct ratio with other plant hydrocolloids and gums results in a homogenous cheese sauce with remarkable mouthfeel (Spanier, 1986). They help to bind water, control viscosity of the sauces and contribute to the finished texture (Burrington, 2003). Heating conditions, pH, and dispersibility are important factors for the evaluation of hydrocolloids used in cheese sauce production (Saha & Bhattacharya, 2010).

5.9 | Starch

Starch has many important functions in the process of making cheese sauce such as participating in controlling viscosity and binding water, which affects the final texture of a sauce (Spanier, 1986). Furthermore, starches are used to reduce production costs, extend the shelf life, reduce recipe costs, and simplify label declaration (Taggart & Mitchell, 2009). Starches contain amylopectin which has different functions and occur in various amounts. Usually, waxy-type starch is used in cheese sauce production because of the high amount of amylopectin. This starch has a specific structure that can give the sauce a smooth texture. Waxy starches are not equal; some offer more benefits than others. For instance, to produce cheese sauces, rice starches with a small particle-size 323 range of 2–8 μm are often used, giving a smooth texture (Burrington, 2003). Also used in production are tapioca, corn, wheat, and potato starches (Sheldrake, 2003). High amylopectin content also determines the stability of the cheese sauce used in a frozen product, affecting such features as silky sheen and flavor. Rice starches can also be mixed with other ingredients, for example, carrageenan or xanthan gum to ensure better stability of the cheese sauce (Burrington, 2003).

Selection of the starch that will be used in production depends on the process itself and the pH of the product. For instance, selection of starches used in dry mixes that are often required because of their convenience and storage stability will depend on time, the temperature of the process, shear, and storage conditions. The same requirements apply to wet sauces (Taggart & Mitchell, 2009). Starch is also used as a substitute for cheese solids to reduce the manufacturing costs of cheese sauces (El-Mahdi et al., 2014). To improve the functional properties of starches, they can be modified. These modifications are aimed at increasing solubility and viscosity or improving gel strength. Also, such modifications enable the starches to be used at higher temperatures or in acidic conditions. In the case of cheese sauces, modified starches are also used for thickening (Fellows, 2016). During the production of a sauce, it is recommended to use one part traditional native starch to two parts of modified starch to improve the quality of the product (Taggart & Mitchell, 2009).

In cheese sauce production, alginates being the salts of alginic acid are often used. Alginic acid is a copolymer of mannuronic acid and guluronic acid. The most commonly used salt is sodium alginate which, due to its unique properties, is useful in the production of food. Sodium alginate allows cheese sauces to suitably adhere to the food product that is consumed, for example, pasta. Alginates are stable at low pH and reduce surface skin formation (Imeson, 2010). Due to their ability to affect the viscosity of the final product, the typical amount used during production varies between 0.3 and 1.0%. One of their functions is to reduce the natural-cheese level and at the same time increase the moisture level in the cheese sauce. Another function is to stabilize the emulsion, reducing fat-loss and improving shelf-life stability of the final product. Alginate is known for its action with calcium ions. Ions that are not sequestered may interact with the alginate and cause additional viscosity. Depending on the ratio of alginate to calcium ions, a solution can be thickened or gelled. They are also used in dry cheese sauces, providing fat-like flow and sheen, which are very important features (Burrington, 2003; Imeson, 2010).

6 | STRUCTURE–FUNCTION ASPECTS

6.1 | Emulsifiers and emulsification

Nowadays, food production requires emulsifiers for use as surface-active lipids. They affect the quality (improve texture) and preservation of the product (Norn, 2015; Sheldrake, 2003). Emulsifiers are substances that, due to their ability to lower surface tension, allow mixing of two immiscible phases such as oil and water. Emulsifiers used in food production have other functions as well, not entirely related to the classical definition—for example, they can modify crystallization or act as a film-forming substance (Norn, 2015).

Currently, emulsifiers are used in many branches of the food industry. Each of them, through their interaction with food, meets the requirements for safety of use. They are, therefore, a group of purified products of natural or near-natural origin. They are used on a large scale mainly in the production of mayonnaises and cheese sauces but also allow dyes to create a uniform color by evenly distributing the ingredients in the entire volume of a product (Dziezak, 1988). Because of the final effects that producers want to obtain, the choice of emulsifier must be considered very carefully and so, there are many publications that deal with the issue of choosing the right emulsifier (McClements, 1999; Robins, 2000; Wendin, Ellekjaer, & Solheim, 1999; Wendin & Hall, 2001).

The process of emulsification helps to achieve the desired cheese texture in a cheese sauce. The emulsifying process is influenced by various factors, for example, the age and type of cheese, pH, temperature, or amount of calcium. Binding of Ca^{2+} ions during the emulsification process is controlled by salts. Monosodium phosphate, disodium phosphate, and trisodium phosphate, used in cheese sauces, have a bacteriostatic effect. Phosphate salts strongly bind calcium when their chain is longer, and they also have an effect on the structure and firmness of cheese sauce. The relative casein content (RCC) is an important factor in this and is determined by the ratio of casein nitrogen to total nitrogen in the cheese that will be melted. Better emulsification in cheese sauces is provided by more intact protein in the cheese production or higher RCC and, regardless of whether or not the source of protein in cheese sauce production is natural cheese or casein, ESs will bind with available protein. Phosphate salts influence the pH of the product, thus, it is good to maintain the range of pH between 5.7 and 6.0 (Burrington, 2003). Emulsified sauces such as cheese sauces, with pH higher than 4.5, can be sterilized to improve their shelf life. To minimize the instability of sauces and color formation, sucrose esters are used and measure the degree to which surfactant is hydrophilic or lipophilic (HLB15-hydrophilic–lipophilic balance). Sucrose ester also improves the appearance of the product and its taste (Nelen, Bax, & Cooper, 2015).

6.2 | Homogenization

The properties and stability of emulsion-based sauces depend on amounts of ingredients, composition, and processing conditions, for example, homogenization.

Homogenization is a process that creates smaller fat globules causing a richer flavor and better stabilization of the product (Serdaroglu, Öztürk, & Kara, 2015). The effectiveness of homogenization can be stated as the reduction of fat globules' size as an outcome of the process (Narvhus, Østby, & Abrahamsen, 2019). During homogenization, to reduce the interfacial tension, emulsifiers adsorb to the fat droplet surfaces. The layer of adsorbed emulsifier molecules also prevents further droplet breakup when they collide with each other within the homogenizer (Degner, Chung, Schlegel, Hutkind, & McClements, 2014). Process of homogenization improves fat emulsion stability, have impact on consistency, structure, smoothness, and appearance of final product (Sargento Food Ingredients, 2017).

In Patent No. 5,731,026, its authors state that depending on the type of homogenizer, the process conditions can be different. For example, if a piston homogenizer is used, the pressure can reach from 7 to 140 bar (Krumhar et al., 1998).

Inventors in Patent No. US 6,893,675 B1 suggest that homogenization can be carried out in two stages. First at 2,500/500 psi in a high-pressure dairy homogenizer and then after another ingredient addition. But as they suggest, it is not a necessary step. Sometimes final mixture of acidified imitation of cheese sauces could be created in a single stage mix, with or without homogenization (Jacobson & Schalow, 2005).

TABLE 2 Examples of the offer of cheese flavors based on the manufacturer's website (Culinaria, 2019)

Index	Name	Dosage, g/kg
AF CF100/005	Emmentaler aroma	1–3
AF CF101/001	Parmesan aroma	1–3
AF CF101/008	Cheddar aroma	3–5
AF CF99/001	Gouda aroma	1–3
AF CF102/004	Blue cheese flavor	1–3
AF CF104/003	Camembert aroma	1–3
AF CF90/002	Brie aroma	1–3
AF CF98/001	Gorgonzola aroma	1–3
AF CF95/001	Feta aroma	1–3
AF CF90/005	Mozzarella aroma	1–3

7 | CHEESE AROMA/FLAVOR

Cheese sauces should get most of their flavor from their main component—cheese. Cheese sauce may contain from 50% cheese to no cheese at all. This means that natural and artificial flavors can be added to final product in various combinations and proportions (Gamay & Schumacher, 1999). Cheese flavor is also developing due to enzymes used during the production process; to reduce production costs, producers use EMC, which is added to immature cheese (Noronha, Cronin, O'Riordan, & O'Sullivan, 2008).

Cheese aromas are a group of the most abundant flavor compounds used to enhance the intensity of taste and smell. Sometimes, they can be added to the cheese sauces to provide stronger or richer cheese taste and aroma (Table 2). We distinguish the aromas of hard cheeses, mainly Parmesan and Emmentaler, semi-hard—Cheddar, Gouda, Provolone, semi-soft-Camembert, Gorgonzola, Romano, Brie, and fresh-Mozzarella and Feta (Culinaria, 2019). The characteristic taste of these cheeses arises due to the metabolism of protein, lactic acid, fat, and citrate during the ripening process. Aroma compounds affect the formation of a characteristic smell of cheese and the taste is obtained by water-soluble substances such as organic acids or amino acids, peptides, and salts (McSweeney & Sousa, 2000).

8 | A REVIEW OF THE PROCESS

8.1 | Enrichment of cheese sauces

Due to the ongoing research on cheese sauces, researchers have managed to identify several ways of their production. These processes give an opportunity to create the desired appearance and taste. All processes are based on the use of new ingredients as substitutes for natural cheese or are used to shape new product features. Therefore, innovative cheese sauces can be obtained through the use of essential oils, soy proteins, modified starch and skimmed cheese, along with milk proteins (Table 3).

8.2 | Production technology

8.2.1 | With essential oils

Essential oils are concentrated liquids extracted from several parts of plants. They are a good source of bioactive compounds, possessing antimicrobial and antioxidative properties (Tongnuanchan & Benjakul, 2014). The process of producing a cheese sauce with essential oils begins with the composition of the mixture, which mainly consists of animal fats (butter oil), lactic acid, WPC, skimmed milk powder, sugar, ESs, water, and selected essential oils. Then, the ingredients are mixed together for about 1 min. After obtaining a required consistency, the mixture is placed in a special heating device and heated to 85°C for about 15 min. At this point, the cooking process takes place using steam, operating at a pressure of 1.5–2 kg/cm^2. After completing this stage, we obtain a final cheese sauce enriched with essential oils and characterized by its high quality due to the omega-3 fatty acids present in its composition, linolenic acids, and, in addition, a new color and increased durability during storage (Shalaby et al., 2017).

8.2.2 | With soy proteins

Soybean proteins have been shown to lower cholesterol and reduce the risk of cardiovascular diseases. They also have very good processing ability for emulsifying, gelling, and water/oil-holding capacity among others (Nishinari, Fang, Guo, & Phillips, 2014). Cheese sauce production based on soy proteins begins with the technology of cheese grinding. This process involves the use of more cheese substitutes. First, cheeses are cut into smaller portions, then ground and mixed together with the appropriate amount of ingredients such as food proteins, skimmed milk powder, butter oil, sodium chloride, nisin, stabilizers—mainly starch and ESs. All components are mixed for 1 min and then treated with hot steam under high pressure for about 10 min at 85–90°C. After the intended time, they are cooled at room temperature, giving a product with a smooth consistency and improved functional properties (Saad et al., 2016).

8.2.3 | With modified starch

Many food processors require starches with better functional properties than those provided by native starches. Modification is provided to improved specific functionalities of the final product. For instance, greater tolerance to high temperatures, pH fluctuations, and all other conditions of the process (Huber & BeMiller, 2017; Wrigley, Corke, Seetharaman, & Faubion, 2016).

Cheese sauces production with the addition of modified starch is more complicated than other previously described processes. During this process, it is important to ensure adequate homogenization of the starch before the gelatinization process (Krumhar et al., 1998). Homogenization is crucial in order to improve the process and give a suitably smooth and simultaneously stretchable texture (Köhlera & Schuchmann, 2011). Accordingly, a water-in-oil emulsion is prepared consisting of 13% cheese, 6% homogenized modified corn starch, and 1% natural starch

TABLE 3 Ingredients that can enrich cheese sauces based on Carpenter, Chen, Gonsalves, Hasenhuettl, and Silver (2004); Shalaby et al. (2017); O'Regan, Ennis, and Mulvihill (2009)

New component/example	Properties	Function in cheese sauces
Essential oils—volatile aroma compounds/ cardamom oil, onion oil, paprika and rapeseed oil	Oily liquids	Antibacterial and antioxidant functions, which makes them an ideal substitute among preservatives used in food products
	Extracted by steam distillation from various parts of plants such as flowers, bark, roots, leaves, seeds, fruits and even wood	They give a new color, taste to cheese sauces
	They can take a variety of flavors and aromas, which are regulated by the amount and types of ingredients contained in oils	They increase durability They give new qualitative properties
Soy proteins/soy	They have a rich set of amino acids and especially exogenous arginine	Giving a new texture
	They have low content of lactose and gluten	New sensory properties of the product
	They lower the level of LDL cholesterol They reduce muscle catabolism They exhibit anti-carcinogenic effects	Providing physicochemical stability, durability and the desired taste sensation
Modified starch	Modified starch is a natural starch exposed to physical factors such as temperature and pressure and chemical factors such as chemical and enzymatic substances	A smooth and stretchy texture
	Improving its functional properties, giving the characteristic and at the same time new taste	Increased durability and flexibility
	The use of modified starch in the production of cheese sauces requires homogenizing them before the occurrence of the gelation process	Improved overall appearance and taste of cheese sauces
Defatted cheese	Cheese is prepared from skimmed milk	Increasing humidity
Milk protein	Biological activities associated with the intact proteins	Lowering the fat content in their composition
	Biological activities associated with amino acid sequence	

relative to the total weight of the sauce. In addition, proteins, ESs, water, maltodextrins, soybean oil, wine vinegar, and small amounts of carrageenan with caramel dye are used. All ingredients are added in a specific order to water at 50°C placed in a high-shear mixer. The content is mixed until the cheese is completely dissolved. The oil and starches are then added, and the mixing process is continued for about 5 min. After the mixing time, the last ingredients added are vinegar and caramel dye, which form a homogeneous mixture. That mixture is in turn homogenized at a pressure of about 14 bar at 50°C. The final stage of the sauce production is the processing of the homogenized mixture at 137°C for 20 s, cooling to 35°C, and the final aseptic filling (Krumhar et al., 1998).

8.2.4 | With defatted cheese and milk protein

Production of cheese sauce based on the addition of defatted cheese and milk proteins has been one of the most beneficial techniques of its enrichment so far. The product obtained in this way is characterized by high humidity, low fat content, and at the same time maintaining durability for 24 weeks. It has a stable taste and desirable texture (Hine, 1994). Defatted cheese is classified as semi-soft because of humidity levels in the range between 61 and 69% (Corvalho et al., 2018). The production of cheese sauce in this way begins with grinding the skimmed cheese. Then, cheese is placed in a special oven along with powdered milk with a moisture content of 5% and a small amount of water. Mixing and heating with steam begins and continues until the temperature reaches 71°C. Once the given value has been reached, steam access is temporarily shut off and other ingredients are added to the mixture—sodium hexametaphosphate, tapioca starch, and xanthan gum. Then, when the steam is in use again, the heating process takes place at 88°C, with simultaneous mixing. For about 2 min, an elevated temperature is used to gelatinize the starch and allow hexametaphosphate to interact with the casein in the skimmed milk and powdered milk. In the final stage, a temperature of 135°C is applied to the resulting homogenous mixture for a period of 23 s, followed by aseptic packing at 38°C and cooling to 22°C. The resulting cheese sauces have not only humidity near 80% but also a stable texture and high durability (Hine, 1994).

9 | STABILITY AND SHELF LIFE

Water activity (A_w) is one of the main features that limit the shelf stability of the product. High water content creates more favorable conditions for mold and fungus growth and also affects bacterial proliferation. In packaged cheese sauces that contain free space inside, it can be observed that water molecules leave the food and spread into the surrounding atmosphere (Yousef & Balasubramaniam, 2013). The A_w is related to the pH of the cheese sauce; according to the FDA, food product with a pH of more than 4.6 is shelf-stable only if its water activity is 0.85 or less. In cheese sauces, the pH is 5.8 (Gamay & Schumacher, 1999).

To provide stability and extend shelf life, producers use many different ingredients, for example, cheese powder or milk powder. One of the main advantages of cheese powder is its higher durability associated with low water activity. This stability allows long-term storage without any changes in the quality of the product and it is easier to combine them with other dry ingredients, as opposed to cheeses which should be subjected to proper treatment before their use in production (Fox et al., 2004). Improving the stability and shelf life of the finished product is also associated with hydrocolloids and emulsifiers which have been described in the previous chapter.

10 | MICROBIOLOGY OF CHEESE SAUCES

Because of high water activity (A_w) levels in cheese sauces, the final product is exposed to increased bacterial growth. To inhibit microbial growth, it is important to add preservatives as the right compounds will inhibit pathogen growth over time and increase the shelf-life of the final product.

To ensure the biological safety of the cheese sauce, the A_w level in the product should be below 0.85 and, therefore, limiting A_w in foods has become an important method for preventing microbial decomposition of the final product (Lee et al., 1991).

Preservatives are additional substances used mainly to extend the durability of a given product. Both natural and synthetic forms can be distinguished. Their task is to prevent unfavorable biological, chemical, physical, and microbiological changes (Wedzicha, 2003).

One of the patents describes polycyclic peptide antibacterial—nisin, as a substance which is used to prevent microbial growth. It needs to be added in amounts up to about 500 ppm of the total cheese sauce formulation which is the maximum value approved by the FDA for sauces. According to Gamay et al. (2011), a maximum level of nisin should be used because it degrades over time. In countries that have not approved nisin as a preservative, dextrose could be used. Saad, El-Mahdi, Awad, and Hassan (2015) reported that the addition of preservatives (nisin; nisin + potassium sorbate; nisin + natamycin + potassium sorbate; nisin + natamycin) to processed cheese sauces obtained on the basis of Ras cheese resulted in a pH in the range of 5.83–5.85. In turn, control samples with no added preservatives showed a pH value approximately 5.82 (Saad et al., 2015).

Gouda and El-Zayat (1988) found that preservatives had no effect on the pH value of processed cheese spreads. These authors suggested that this could be associated with the ingredients added during blending, especially Ras cheese being in higher amounts in the control sample. However, after 3-months storage at room temperature, the pH values of processed cheese sauces with preservatives decreased slowly in all samples, until the end of the storage period (Saad et al., 2015). The authors reported that the decrease was more noticeable in the control samples without preservatives added and could be associated with the activity of the microorganisms present and propagated during the storage at room temperature. Moreover, the enzymatic activity of the resistant enzymes present in cheese sauces, polymerized phosphate occurrence (ESs), and their interaction with proteins, lactose hydrolysis, can influence the reduction in the pH during the storage period (Saad et al., 2015).

11 | SENSORY ASPECTS OF CHEESE SAUCES

All innovative products and new recipes, including the discussed cheese sauces, are created due to market requirements and consumer tastes; therefore, the assessment of finished products in terms of organoleptic and visual properties is very important (Esmerino et al., 2017). Even small changes in the formula of the product may affect the taste or visual impression of consumers. To better understand consumer needs, men and women of all ages should be invited for sensory tests. Research on such a diverse group will give a more complete picture regarding the quality and evaluation of the final product (Oliveira et al., 2017; Torres et al., 2017). In the early stages of product development and consumer research, focus groups are one of the main tools. This method is based on group meetings with the participation of a moderator with a carefully stimulated group of people. In a comfortable and friendly environment, it is easier to get opinions and attitudes about certain products (Esmerino et al., 2017).

Sensory analysis techniques are major tools for evaluation of the product. Because of this, it is necessary to use consumer opinions to obtain a sensory description of the evaluated products and recommendations for its reformulation. To perform this task, it is recommended to use the so-called intensity scales and the method that would describe and accurately review cheese sauces in organoleptic and visual aspects is check-all-that-apply (CATA). Questions included in the survey are one of the quickest ways that have been introduced in sensory analysis, it is easy to implement, and not annoying to consumers (Oliveira et al., 2017; Torres et al., 2017). In the CATA questionnaire, consumers are asked to choose from a 9-point rating scale the point that describes in the best way the individual aspects of the tested product. On this scale, 1 is synonymous with "extremely dislike" and 9 means "extremely like" (Oliveira et al., 2017). In describing cheese sauces, consumers have to be asked about such factors as appearance of the product and due to the great variety of cheese sauces and their rich taste and aroma, the scale used in the study should be extensive and well-described. In order to describe sensory characterization of requeijão cremoso, a spreadable processed cheese, used five groups to describe individual features being appearance (color and brightness), aroma and flavor (the scale associated with the studied product), visual texture (consistency, spreadability, adhesiveness, gelatinous quality, and homogeneity) (Torres et al., 2017).

Another way to examine and evaluate consumer tastes are projective techniques, imported from other areas for application in sensory science, which have been used in marketing and consumer studies based on subjective opinion. In this method, there are no right or wrong answers (Soares et al., 2017), they consist of a set of qualitative techniques in which a person can present their personality, attitude, and opinions. They are considered noninvasive approaches and one of these techniques is the word association task, an effective method in which respondents are asked to share their first impressions related to the presented product—their thoughts and feelings (Esmerino et al., 2017).

Both methods can be used during product testing. Each of them focuses on researching the consumer market and consumer tastes. However, the first described technique is less onerous for consumers and requires less energy and resources by producers. It also helps to acquire a lot of data faster and the study can be done on a large number of people from different age and social groups which strongly affects the knowledge obtained by the researchers.

12 | NEW DIRECTIONS IN CHEESE SAUCE PRODUCTION

In recent years, more and more scientists have been trying to use bacteriocin or bacteriocin-producing bacteria to control contamination of final products by microorganisms. It is believed that in the future, it will be an alternative for food additives. One of the potential bacteriocins that have been studied, is pediocins produced by *Pediococcus* spp. Commercially available under the name Alta2341TM or MicrogardTM, Pediocin (PA-1) was found to reduce *Listeria monocytogenes* counts in cheese sauce. Also, researchers verified the ability of pediocin to effectively reduce *Staphylococcus aureus* counts and enhance the shelf life of other raw dairy product (Silva, Silva, & Ribeiro, 2018). Moreover, in 2016, researchers became interested in research associated with food production systems that use advanced thermal processing methods. Transversal acoustic vibration turned out to be an efficient mechanism to enhance the cooling process of highly viscous food products such as cheese sauce (Stoforosa, Farkas, & Simunovic, 2016).

Due to the growing interest in cheese sauces products, one of the latest patents describes a cheese sauce that is prepared including a new component, Quillaia—soap bark extract (Meyer, 2018) which can act as emulsifier or foaming agent. In addition, it contains saponins, polyphenols, and tannins (San Martín & Briones, 2000). Another patent from 2016 No. U.S. 9,420,804 B2 described shelf-stable acidified starch and cheese sauce meal. Authors created a meal that combines acidified starch component with pH of about 4.6 or below and cheese-based sauce component with pH between 5.7 and 6.2. Combination of those two ingredients creates ready-to-eat meal (Hong, Morales, & Pasch, 2016). The next example of cheese sauces development is described in Patent No. U.S. 2019/0021386 A1 from 2019. Authors presented method of protein delivery for people with special dietary needs. Inventors suggested that cheese sauce containing dehydrated poultry protein or high solids content can be successfully formulated and mixed with pasta **(**Cappozzo, 2019).

This new research and the interest in cheese sauces production shows that this topic is important to the food industry and, in the future, can play an important role, especially in the dairy industry.

13 | CONCLUSIONS

In recent years, consumers are more and more willingly reaching for cheese sauces. There are a few factors that have influenced this behavior. The first is convenience, as in stores there are available cheese sauces both in powder form and already prepared "wet" sauces. Both types are easy and quick to prepare. Just pour the dry sauce into water or simply heat the "wet" sauce. Consumers can add them to many different dishes as a filling and tasty sauce served hot or cold. Due to their quick preparation, busy people can afford a warm and filling meal during the day. The other aspect affecting the increase in the popularity of cheese sauces is the large selection of these products. Cheese sauces, since their base can consist of various ingredients affecting their texture, viscosity and, above all, taste, are widely consumed by a variety of people.

Currently, due to the development of new processes and the use of new ingredients, the selection palette of various cheese sauces has increased. These processes are based on the use of new ingredients as substitutes for natural cheese, which is important for people with food allergies or intolerance to some of the cheese ingredients. For now, producers can create with success cheese sauces with the use of essential oils, soy proteins, modified starch, and skimmed cheese along with milk proteins.

For scientists and food industry, cheese sauces seem to be an interesting topic. Thanks to both: the legal definition of this product and possibility associated with modification of individual components. Research in terms of both microbiology and the structure of this product itself is associated with great potential. In the future, along with the development of new technologies and the impact on such important matters as shelf stability of "wet" cheese sauces, and also the creation of methods of dealing with microorganisms spoiling these products, the consumption of cheese sauces may increase even more.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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Effect of whey protein concentrate on physicochemical properties of acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat

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ABSTRACT

The aim of the work was to estimate the effect of whey protein concentrate (WPC80, 2–8 g/100 g) on physicochemical properties of processed cheese sauces obtained on the basis of acid casein (AC) and coconut oil (OCO) or anhydrous milk fat (AMF). Experiments proved that the use of coconut oil and anhydrous milk fat with addition of different contents of whey proteins affected the structure and appearance of processed cheese sauces. Increasing the concentrations of WPC80 increased the hardness and adhesiveness (OCO: 2–7 g/100 g WPC80; AMF: 2–8 g/100 g WPC80), as well as apparent viscosity (OCO: 2–7 g/100 g WPC80; AMF: 2–8 g/100 g WPC80) of cheese sauces. Storage modulus (G') was higher than the loss modulus (G'') during the whole experiment (in both types of sauces). The color intensity of all evaluated products was characterized from light to dark creamy. The density of processed cheese sauces with OCO was higher than that of samples with AMF, while the water activity did not change with increasing the WPC80 content ($P > 0.05$).

1. Introduction

Fast lifestyle and the lack of time to prepare meals during a day, also change of eating habits related to many food allergies and conscious consumer choices, caused a market demand for ready-made food. One of these food products are cheese sauces. In recent years, we could observe an increase in the consumption of cheese-based dips and cheese sauces. It is predicted that cheese sauces market will be constantly growing through the forecasted period of 2017 until 2022 (Orbis Research, 2017).

Cheese sauces/processed cheese sauces belong to the group of high moisture products with high water activity, which have no strict standards or legal definitions. For this reason, they may contain mixture of ingredients of dairy or non-dairy origin (Saad, El-Mahdi, Awad, & Hassan, 2015; Salek et al., 2019).

Natural cheese is the most commonly used base for the production of cheese sauce. It affects the flavor, body, texture and mouthfeel of the product (Banes, Helm, & Taylor, 2014). Due to the cost and period of validity of the cheese substitute, more often the manufacturer begins to reach for dry semi-finished products, and because of that, dehydrated cheese (e.g. cheese powder) is often used in production of cheese sauce (da Silva, Ahrné, Larsen, Hougaard, & Ipsen, 2018). Dried dairy products contain ingredients like milk powders and protein powders such as whey protein concentrate (WPC) or whey protein isolate (WPI) (Hu & Jacobsen, 2016). Whey proteins contain bioactive fractions like lactoferrin, which is able to bind iron (Zapata, Singh, Pezeshki, Nibber, & Chelikani, 2017). It is also characterized by antibacterial, antiviral, antitumor (Gupta & Prakash, 2017), antifungal properties and has a positive effect on the human nervous system (Darewicz, Iwaniak, & Minkiewicz, 2014), immunoglobulin and alpha-lactalbumin, which is involved in the regulation of calcium management (Zapata et al., 2017). Also, important factor of choosing the whey proteins as a component is their solubility (Guimarães & Gasparetto, 2005). WPCs affect the properties of food systems such as flavor and texture, hydration, visual and rheological features (Onwulata & Huth, 2009). Whey proteins not only positively affect the consumers' health and texture of food products, but have also an effect on the finances of food companies by reducing the costs of raw materials and production (Božanić, Barukčić, Jakopovic, & Tratnik, 2014; Singh & Singh, 2012). Another component used in processed cheese sauces formulation is acid casein. (Chavan & Jana, 2007) in their paper described that the main protein source in dairy-based analogue cheese products is caseinate or rennet casein,

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however, acid casein has higher water binding capacity compared to rennet casein (O'Connell & Flynn, 2007). Acid casein was used before with positive effect in manufacturing of processed cheese analogues (Sołowiej et al., 2015).

Anhydrous milk fat (AMF) and organic coconut oil (OCO) were used to prepare the model processed cheese sauces. The use of AMF in the research is connected with its physical and health-promoting properties. It was reported that AMF causes a decrease in the concentration of LDL (low-density lipoprotein), VLDL (very low density lipoprotein), decreased liver total cholesterol and cholesterol esters. Also, it has an impact on secretion of inflammatory leukotrienes and thromboxanes (Herrera-Mezai et al., 2013). Its crystallization and melting properties affect the sensory and functional attributes of products, to which it is added (Wang, Li, Han, Li, & Zhang, 2017). On the other hand, virgin (organic) coconut oil used in our research is described as the product with numerous beneficial health effects e.g. lowered total triglycerides, phospholipids, LDL and cholesterol levels and increased HDL cholesterol (Gopala, Gaurav, Ajit, Prasanth, & Preeti, 2009). Also, coconut oil has antiviral, antifungal and antibacterial properties. It helps in diseases such as pneumonia or urinary tract infections (Gopala et al., 2009). Research on descriptive sensory evaluation of virgin coconut oil and refined, bleached and deodorized coconut oil is very important for producers as they may use this component as the ingredient in the final product (Villarino, Dy, & Lizada, 2007).

To the best of our knowledge, there is no research about properties and features describing processed cheese sauces based on acid casein and anhydrous milk fat or coconut oil. Also, addition of WPC80 is desirable because of its health-promoting properties. In addition, studies on features describing the processed cheese sauces, such as density, have never been conducted. Therefore, the aim of the work was to test the effect of whey protein concentrate (2–8 g/100 g WPC80) on physicochemical properties (texture, viscoelastic properties, density, color and water activity) of processed cheese sauces obtained on the basis of acid casein and coconut oil or anhydrous milk fat.

2. Material and methods

2.1. Materials

The following raw materials were used for the production of processed cheese sauces: whey protein concentrate (WPC80, 76.8 g/100 g proteins, Milkiland EU Ltd., Warsaw, Poland), acid casein (AC, 92.1 g/100 g proteins, PPHU Polsero, Sokołów Podlaski, Poland), anhydrous milk fat (AMF, 99.8 g/100 g fat content, Mlekovita, Wysokie Mazowieckie, Poland), organic coconut oil (OCO, Bio Planete, Lommatzsch, Germany), carrageenan (TIC GUMS, Belcamp, MD, USA), disodium phosphate, lactic acid, sodium hydroxide (PPH POCH, Gliwice, Poland).

2.2. Preparation of processed cheese sauces

AC (6 g/100 g) and WPC80 (2, 3, 4, 5, 6, 7 or 8 g/100 g) were mixed with distilled water using a magnetic stirrer (Heidolph MR 3002S, Schwabach, Germany) (21 °C, 300 rpm). Then 10 g/100 g of AMF or OCO (constant value for each sample, melted at 45 °C) was added and ingredients were placed in a container and mixed using the H 500 homogenizer (Pol-Eko Aparatura, Wodzisław Śląski, Poland) for 2 min at 10,000 rpm. Disodium phosphate (0.8 g/100 g) and carrageenan (0.3 g/100 g) (carrageenan was dissolved and constantly mixed for 15–20 min in a water bath at 70 °C to obtain a semi-liquid consistency) were added, pH was adjusted to 5.8 using lactic acid or sodium hydroxide (2 mol/L), the mixture was immersed in 80 °C water bath and the contents were mixed at 10,000 rpm for 10 min, according to the method proposed by Sołowiej et al. (2015). Finished processed cheese sauces were poured into plastic containers. The samples were cooled at room temperature for 30 min, and after that, they were refrigerated overnight at 4 °C. Cheese sauces were removed from the refrigerator 1 h before analyses in order to reach the temperature of 21 °C. Because of the consistency of samples, texture and viscosity measurements were carried out in plastic containers (cylindrical, sample size - 40 mm in diameter and 40 mm in height). Every sample was prepared in triplicate.

2.3. Penetration test

All measurements were carried out using the TA-XT2i Texture Analyzer (Stable Micro Systems, Godalming, Surrey, UK) according to the protocol described by Fox, McSweeney, Cogan, and Guinee (2017). Processed cheese sauces were penetrated by a 15 mm diameter cylindrical probe to the depth of 28 mm. The penetration rate was 1 mm/s. Processed cheese sauces were evaluated for their hardness and adhesiveness using Texture Expert software. Five measurements were carried out for each of the three replicates.

2.4. Viscosity

Apparent viscosity of processed cheese sauces was investigated using a Brookfield DV II+ rotational rheometer (Brookfield Engineering Laboratories, Stoughton, MA, USA) equipped with a Helipath Stand and T-bar spindle D. Measurements were carried out at 21 °C with spindle velocity of 0.5 rpm according to the method described by Sołowiej et al. (2015).

2.5. Viscoelastic properties

Storage (G') and loss (G'') moduli of cheese sauces were measured applying Kinexus lab+ rheometer (Malvern Panalytical, Cambridge, United Kingdom) using serrated plates (PU40X SW1382 SS and PLS40X S2222 SS, at plate – plate configuration). Measurements were made at 21 °C and frequency of 10 Hz. Results from measurements were computer-registered in the Kinexus Malvern program - rSpace.

2.6. Colorimetric measurements

Colorimetric measurements were performed with the Minolta CR-221 chroma meter (Minolta, Osaka, Japan) with the diameter of estimated measuring area of 3 mm. The CIE Lab color scale (L*, a*, b*) specified by the International Commission on Illumination (Commission Internationale de l'Éclairage, CIE) was used. The measurements for each sample were performed in triplicate according to the method described by Sołowiej et al. (2015); Muszyński et al. (2017).

2.7. Water activity

Water activity (a_w) was measured using the Aqua Lab 3 TE water activity meter (Decagon Devices Inc., Pullman, WA, USA) with the accuracy of ± 0.001 of a_w unit. Before measurement, the apparatus was calibrated with the Rotronic humidity standard (95% HR). Measurements were performed at the temperature of 22 °C, in five replications. For each sample, two outliers were classified as defective and were excluded from further analysis.

2.8. Density

Density measurements were performed with a gas pycnometer (AccuPyc 1330; Micromeritics, Norcross, GA, USA) at the temperature of 22 °C (Sołowiej et al., 2015). Analyses were performed in three replications.

2.9. Statistical analysis

Statistical analysis was carried out in the STATISTICA 12.0 PL

Table 1
Effect of WPC80 concentration on processed cheese sauces texture attributes obtained on the basis of AC with OCO or AMF.

Oil/Fat	Content of WPC80 [g/100 g]	Texture attributes	
		Hardness (N)	Adhesiveness (J)
AC and OCO	2	$0.11^a \pm 0.003$	$3.42^a \pm 0.30$
	3	$0.13^b \pm 0.005$	$22.88^b \pm 0.88$
	4	$0.18^c \pm 0.004$	$103.32^e \pm 2.51$
	5	$0.20^d \pm 0.007$	$142.09^g \pm 1.39$
	6	$0.20^d \pm 0.006$	$176.94^i \pm 0.47$
	7	$0.29^e \pm 0.017$	$159.03^h \pm 3.67$
	8	$0.18^c \pm 0.009$	$62.58^d \pm 0.78$
AC and AMF	2	$0.11^a \pm 0.009$	$39.38^c \pm 0.63$
	3	$0.15^b \pm 0.003$	$102.09^e \pm 1.39$
	4	$0.15^b \pm 0.003$	$112.82^f \pm 4.18$
	5	$0.15^b \pm 0.001$	$159.12^h \pm 7.93$
	6	$0.88^f \pm 0.006$	$232.47^j \pm 3.67$
	7	$0.93^g \pm 0.007$	$384.47^k \pm 2.68$
	8	$0.98^h \pm 0.15$	$392.69^l \pm 1.1$

Data are presented as means ± SD (standard deviation).
[a-l] Means in the same column with different superscripts are significantly different ($P < 0.05$, Tukey's HSD test).

application (StatSoft Polska Sp. z o. o., Kraków, Poland). A two-way (protein concentration and type of oil/fat) ANOVA was performed, and significant differences between samples were determined by Tukey's post-hoc test at $P < 0.05$.

3. Results and discussion

3.1. Penetration test

The influence of different WPC80 contents on the hardness and adhesiveness of the obtained processed cheese sauces on the basis acid casein (AC) and OCO or AMF is presented in Table 1. Generally, hardness of the final product increased with the amount of added WPC80 in products with AMF and OCO (2–8 g/100 g and 2–7/100 g, respectively) ($P < 0.05$). The greatest hardness characterized cheese sauce with 7 g/100 g WPC80 (0.29 N, OCO) and 8 g/100 g WPC80 (0.98 N, AMF) (Table 1), while the lowest hardness characterized the sauce obtained with a 2 g/100 g WPC80 (0.11 N) in both tested cheese sauces.

Sołowiej, Gustaw, and Nastaj (2008) found that the addition of whey protein concentrates: WPC35 and WPC65, increased the hardness of cheese analogues compared to products obtained solely from acid casein. Authors suggested that because the amount of protein increased, structure of final products became more compact and therefore harder. The results obtained in our research also confirm this conclusion, but only to some point. Statistically significant increase in hardness, with regard to samples with AMF, was observed from cheese sauce with 6 g/100 g WPC80 ($P < 0.05$). We believe that this result was affected by the type of whey concentrate used in our experiment. WPC80 has the lowest moisture and lactose content, and the highest protein content comparing to WPC35, WPC50 and WPC65 (Chandrapala, 2019). In connection with the above, lower amounts of added WPC80 did not cause any substantial increase in the product hardness. We also observed differences in hardness with regard to the fat that was used for production. AMF is a mixture of triacylglycerols with comprised of more less 60 different fatty acids (Dimick, Reddy, & Ziegler, 1996), In turn, OCO contains saturated fatty acids occurring in the form of triglycerides, but most of them are lower chain saturated fatty acids (Gopala et al., 2009). This structure can be related with this unequal increase in hardness in the case of cheese sauces on the basis of OCO with the highest amount of WPC80.

Table 1 illustrates an increase in hardness and adhesiveness of product with addition of AMF and OCO. In samples with the addition of AMF, the greatest adherence characterized cheese sauces with 8 g/100 g WPC80 content (392.69 J), while the smallest with 2 g/100 g WPC80 (39.38 J). In processed cheese sauces with OCO and 8 g/100 g WPC80, described features were lower compared to the product with 2–7 g/100 g WPC80. Adhesiveness and hardness of product with OCO (Table 1) decreased by 65.52 J and 0.18 N, respectively. The most important WPC functions of low fat products are: water binding, emulsification, gelation and increasing product adhesion (Królczyk, Dawidziuk, Janiszewska-Turak, & Sołowiej, 2016). Whey proteins act like fat globules and due to that, reduction of cheese used in the production can be implemented, which however increases the product adhesiveness (Banes et al., 2014). Moreover, whey proteins adsorption onto the surface of fat globule is selective. It is influenced by factors like pH, presence of salts, temperature and protein concentration (Yamauchi, Shimizu, & Kamiya, 1980). During our experiment, we could observe that hardness and adhesiveness of samples with OCO increased from 2 to 7 g/100 g WPC85 and then decreased after adding greater amounts of whey protein concentrate. Despite that the hydrophobic interactions between fats and proteins must play an important role (Shimizu, Kamiya, & Yamauchi, 1981). Our result may suggest that hydrophobicity of proteins and their amount are not always the factors which determine the highest adsorption at fat-water interfaces during emulsification. Product obtained on the basis of OCO with 8 g/100 g WPC80 has reached the limit and did not bind supplied proteins. Moreover, adhesiveness can be a positive and negative attribute. Controlled agglomeration or granulation can be beneficial aspects of stickiness/adhesiveness feature. Surface with adhesive property has the ability to agglomerate some particles. In the result, granules dissolve very well on reconstitution (Adhikari & Bhandari, 2009). Adhesiveness of a product can be also a major problem during production of processed cheese/processed cheese analogues. It can cause the process difficulties, because it can stick to some interior parts of the equipment during production steps. In addition, higher adhesiveness entailed processed cheese to be hard to detach from the packaging material when opening, which is adversely perceived by consumers (Sołowiej et al., 2020). Also, it affects the slicing of processed cheese (Awad, Hassan, & Mistry, 2010). In turn, with regard to cheese sauces, their greater adhesion is desirable, because the sauce should stick to the product, e.g. in the case of snacks, chips, etc. This feature is really important for consumers, especially in products like sauces.

3.2. Viscosity measurement

The effect of WPC80 concentration (2–8 g/100 g) on the apparent viscosity of the processed cheese sauce obtained on the basis of acid casein and OCO or AMF has been shown in Fig. 1. Viscosity of cheese sauces with OCO (1946 Pa s (2 g/100 g) - 8300 Pa s (8 g/100 g)) and AMF (2394 Pa s (2 g/100 g) - 6600 Pa s (6 g/100 g)) increased with the increase in WPC80 content ($P < 0.05$). Also, there was a significant decrease in product with 7 g/100 g and 8 g/100 g WPC80 and AMF (3440 Pa s and 2518 Pa s, respectively) ($P < 0.05$).

Differences between viscosity occurring in samples were related to the amount of WPC80 content and sources of oil/fat used in the production of sauces. Corredig and Dalgleish (1999) studied interactions of α-lactalbumin, β-lactoglobulin and casein, and proved that these proteins combined during the heat treatment, resulting in an increase in the viscosity of the finished product. Brunello, McGauley, and Marangoni (2003) suggested that hardness of a fat that is used in food production, is a parameter that affects the perceived texture of a food product. Coconut oil predominately contains medium-chain triglycerides (MCTs). This type of triacylglycerols are specific lipids. Only two plant fats, which are coconut and palm kernel oils, contain this type of fatty acids (Gopala et al., 2009). Anhydrous milk fat is a complex structure of triglycerides. They contain several fatty acids of different carbon chain length and varying degree of saturation (Huber, Molero, Pereyra, & Ossa, 1996). Additionally, composition of protein source

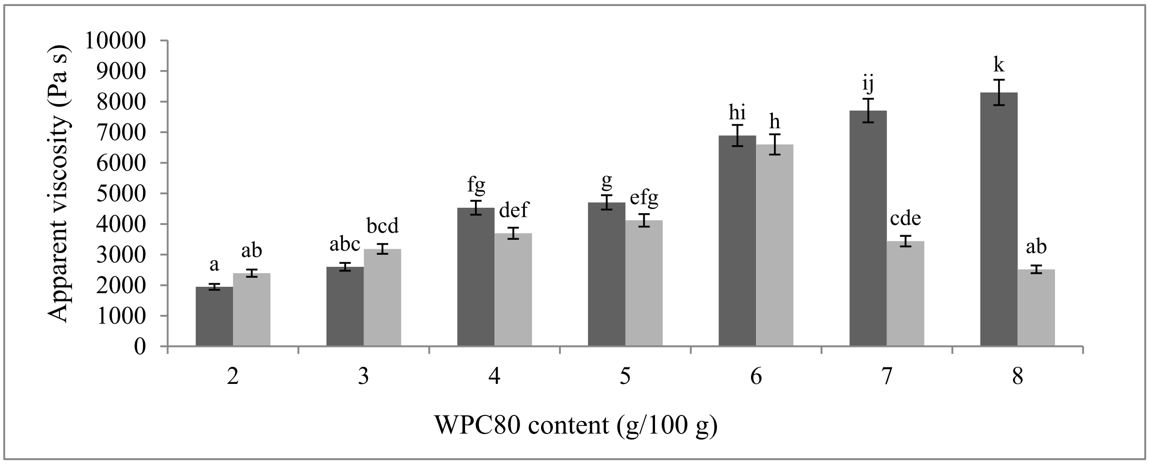

Fig. 1. Effect of different WPC80 concentrations (2–8 g/100 g) on apparent viscosity of processed cheese sauces obtained on the basis of AC and OCO (dark grey bars) or AMF (light grey bars).
[a-k] Means with different superscripts are significantly different ($P < 0.05$).

used in a production also affects the final product structure. Food proteins are a mixture of several proteins, thus competitive adsorption and stability of interfacial film occurs between them depending on the initial ratio of protein components (Damodaran, 2017). Shimizu et al. (1981) examined adsorption of whey proteins on fat globule surfaces during emulsification process with coconut oil at different pH. Their research showed that the amount of whey proteins adsorbed at pH 5.0 on fat surface was greater compared to other tested pH. The authors observed that most of the surface protein in coconut emulsions prepared at different pH (3.0, 7.0 and 9.0) seemed to be tightly bounded, compared to pH 5.0-emulsion, where the large amount of loosely-bound proteins was present (Shimizu et al., 1981). In formulation of our cheese sauces, we have used pH 5.8. A steady increase in viscosity may be related to the coconut oil used. Unbound proteins on the surface remain in solution and, in combination with other components, form structures with high viscosity. However, in the case of sauces with AMF, the increase in viscosity was inhibited with the addition of 7 g/100 g WPC80. Taking into account the structure of used oils and the amount of WPC content, which were differentiating factors, changes in viscosity can be caused by internal friction of a moving fluid. Molecule structure of the final product with presented quantities of individual substrates are more ready to flow than samples with high viscosity. The same observation was described by Dimitreli and Thomareis (2008). They concluded that greater amount of proteins can cause the increase in the linear viscoelastic properties.

3.3. Viscoelastic properties

Characteristics of viscoelastic properties of processed cheese sauces containing whey proteins (WPC80), anhydrous milk fat (AMF) or coconut oil (OCO) has been shown in Table 2.

In the tested samples with the addition of OCO and AMF, G' and G'' increased along with the increase in WPC80 content (2–7 g/100 g and 2–8 g/100 g, respectively), which proves strengthening of the gel structure of the tested products. In both tested sauces, the modulus G'' was never higher than the modulus G'. When comparing results of measurements of both products in terms of the fat content, higher moduli were observed in product with AMF, except from cheese sauces obtained on the basis of OCO with addition of 7 g/100 g WPC80, where G' and G'' was 14820.77 Pa and 4986.28 Pa, respectively. We have noted that the storage and loss moduli for both cheese sauces were correlated with the hardness results, indicating that processed cheese sauces obtained with both AMF and OCO were harder. In the sample with 8 g/100 g WPC80 and OCO, a decrease in G' and G'' was noted (as well as hardness – Table 1), which indicated that gel structure of the processed cheese sauce sample became weakened, which caused formation of less elastic system. The reason for these results may be the mineral content of the WPC, and more specifically, the calcium amount. WPC80 contains 423 mg in 100 g of product (Page et al., 2016). As the amount of added WPC80 increases, the Ca content in the product also increases. Biswas, Muthukumarappan, and Metzger (2008) observed that processed cheese with larger content of Ca showed higher G' and G'' than that of low Ca and P content. Differences in measurements between products with OCO and AMF may be related to the origin of both oil/fat. AMF, because of its structure, corresponded better with other ingredients of product, which causes higher G' and G''. Anhydrous milk fat is a combination of fatty acids in a heterogeneous composition because of differences in the chain length, their binding position on the glycerol backbone and their degree of saturation resulting in the generation of thousands of different kinds of TAGs, which in the final product can better interact with the other ingredients (Khamis et al., 2017).

Table 2
Effect of WPC80 on G' and G'' moduli of processed cheese sauces obtained on the basis of AC and OCO or AMF.

Oil/Fat	Content of WPC80 [g/100 g]	G' (Pa) ± SD	G'' (Pa) ± SD
AC and OCO	2	$8.57^{a} \pm 0.14$	$4.16^{a} \pm 0.30$
	3	$70.32^{b} \pm 1.63$	$29.77^{b} \pm 0.24$
	4	$1588.68^{d} \pm 7.21$	$597.57^{d} \pm 6.95$
	5	$3367.24^{e} \pm 1.34$	$1141.96^{f} \pm 8.61$
	6	$6140.77^{j} \pm 1.33$	$2329.09^{j} \pm 1.31$
	7	$14820.77^{m} \pm 2.84$	$4986.28^{n} \pm 2.65$
	8	$3905.39^{i} \pm 4.76$	$1254.69^{g} \pm 4.12$
AC and AMF	2	$473.85^{c} \pm 8.28$	$161.78^{c} \pm 9.29$
	3	$3402.15^{f} \pm 7.24$	$1131.78^{e} \pm 7.73$
	4	$3713.49^{g} \pm 6.08$	$1288.45^{h} \pm 7.19$
	5	$3747.69^{h} \pm 5.64$	$1295.75^{i} \pm 2.09$
	6	$7296.25^{k} \pm 1.17$	$3110.98^{k} \pm 2.54$
	7	$7327.2^{l} \pm 7.56$	$3757.19^{l} \pm 2.88$
	8	$7329.46^{l} \pm 13.26$	$3854.62^{m} \pm 2.22$

Data are presented as means ± SD (standard deviation).
[a-f] Means in the same column with different superscripts are significantly different ($P < 0.05$, Tukey's HSD test).

3.4. Colorimetric measurements

Table 3 present the results of the color analysis of tested processed cheese sauces. The color intensity of the evaluated products was significantly different from each other ($P < 0.05$) and it could be

Table 3
Color analysis of processed cheese sauces according to CIE Lab standards for samples with the basis of AC and OCO or AMF.

Oil/Fat	Content of WPC80[g/100 g]	CIE Lab coordinate			Hue angle H	Chroma C
		L*	a*	b*		
AC and OCO	2	$68.59^{ef} \pm 1.31$	$-1.21^{a} \pm 0.03$	$2.20^{a} \pm 0.37$	$150.88^{a} \pm 3.53$	$2.51^{a} \pm 0.33$
	3	$70.1^{fg} \pm 0.13$	$-1.26^{ab} \pm 0.06$	$3.31^{b} \pm 0.02$	$159.11^{cde} \pm 0.77$	$3.54^{b} \pm 0.03$
	4	$68.45^{e} \pm 0.42$	$-1.26^{ab} \pm 0.04$	$3.33^{bc} \pm 0.15$	$159.24^{cde} \pm 1.40$	$3.56^{bc} \pm 0.12$
	5	$68.3^{e} \pm 1.17$	$-1.39^{c} \pm 0.01$	$3.18^{b} \pm 0.47$	$156.04^{bc} \pm 3.45$	$3.47^{b} \pm 0.42$
	6	$67.36^{de} \pm 0.18$	$-1.36^{bc} \pm 0.02$	$4.01^{de} \pm 0.24$	$161.17^{def} \pm 1.24$	$4.23^{def} \pm 0.22$
	7	$63.44^{a} \pm 0.36$	$-1.67^{hi} \pm 0.03$	$4.17^{ef} \pm 0.49$	$158.19^{cd} \pm 0.57$	$4.49^{def} \pm 0.04$
	8	$64.53^{ab} \pm 0.02$	$-1.79^{i} \pm 0.02$	$4.14^{def} \pm 0.19$	$157.91^{cd} \pm 0.91$	$4.50^{ef} \pm 0.17$
AC and AMF	2	$66.31^{cd} \pm 0.21$	$-1.59^{fgh} \pm 0.02$	$3.28^{b} \pm 0.02$	$152.67^{ab} \pm 0.30$	$3.47^{b} \pm 0.01$
	3	$68.02^{e} \pm 0.03$	$-1.45^{cde} \pm 0.01$	$3.90^{cde} \pm 0.03$	$159.54^{cde} \pm 0.27$	$4.16^{cde} \pm 0.03$
	4	$70.62^{g} \pm 3.34$	$-1.55^{efgh} \pm 0.01$	$3.58^{bc} \pm 0.04$	$156.57^{bc} \pm 0.31$	$3.90^{bcd} \pm 0.24$
	5	$64.45^{ab} \pm 0.47$	$-1.48^{cdef} \pm 0.006$	$4.09^{def} \pm 0.03$	$160.08^{cde} \pm 0.20$	$4.35^{def} \pm 0.03$
	6	$67.32^{de} \pm 0.14$	$-1.42^{cd} \pm 0.006$	$4.59^{f} \pm 0.03$	$162.17^{ef} \pm 1.24$	$4.80^{f} \pm 0.78$
	7	$65.89^{bcd} \pm 0.51$	$-1.64^{gh} \pm 0.09$	$6.23^{g} \pm 0.22$	$165.30^{f} \pm 0.14$	$6.44^{g} \pm 0.24$
	8	$64.83^{abc} \pm 0.07$	$-1.54^{defg} \pm 0.09$	$6.06^{g} \pm 0.1$	$164.96^{f} \pm 0.63$	$7.11^{h} \pm 0.35$

Data are presented as means ± SD (standard deviation).
[a-i] Means in the same column with different superscripts are significantly different ($P < 0.05$, Tukey's HSD test).

characterized from light to dark creamy, because b* in the first case (OCO) was in the range of 2.2 (for 2 g/100 g) to 4.17 (for 7 g/100 g) and in the second (AMF) 3.28 (for 2 g/100 g) - 6.23 (for 7 g/100 g). All tested samples had low a* that indicated a slight green hue. Of all tested sauces, the product with 7 g/100 g WPC80 and AMF was characterized by the highest b* and had the closest shade to yellow compared to the other samples. In the case of a product obtained on the basis of OCO, the highest content of chroma could be observed among samples with 8 g/100 g, 7 g/100 g and 6 g/100 g WPC80 with no significant difference between them ($P > 0.05$). At the same time, these samples were characterized by the highest b* and a* (8 and 7 g/100 g) (more green and yellow tones). The test samples had different hue angles. The lowest one characterized a sample of 2 g/100 g and the highest of 6 g/100 g WPC80 ($P < 0.05$). Each of the tested samples showed brightness (L*) within the interval 63–70. Statistically significant differences for the L* was decreased with the increase in WPC80 content (from 3 to 8 g/100 g) ($P < 0.05$). Cheese sauces obtained on the basis of AMF were characterized by the highest content of chroma in product with the highest content of WPC80 - 8 g/100 g ($P < 0.05$). Sauce with 7 g/100 g WPC80 were highest in b* and a* ($P < 0.05$). These results testify to the occurrence of more green and yellow tones. The lowest hue angle characterized the 2 g/100 g sample (similar to sauces with the addition of coconut oil) ($P < 0.05$), and the highest 7 and 8 g/100 g ($P < 0.05$). Each of the tested samples showed brightness (L*) within the interval 64–71.

Childs, Yates, and Drake (2009) examined two categories of cheese sauces: wet and dry. The sauces used in the study were characterized by an extensive color palette and intensity: from orange and yellow to white or creamy. In conclusions, authors suggested that color attributes had only a minor influence on the consumer preferences. The prime determination of cheese color have light scattered by milk fat globules (Wadhwani, 2011). We also have observed that our processed cheese sauces obtained on the basis of AMF were more yellow than products with OCO. It is caused by β-carotene, which is responsible for AMF color and also during AMF production process, it is partially preserved, giving it owl-like color (Illingworth, Patil, & Tamine, 2009). Crude coconut oil was characterized by different color depending on the process of their preparation: from really light yellow to brownish yellow. Oils used in our research were prepared with normal processing techniques that cause very pale yellow that is not visible for everyone (O'Brien, 2009). Also, OCO does not have compounds that are in AMF structure and because of that, its color is white, which at the end of the preparation process caused processed cheese sauces brightened. In addition, Olsson, Håkansson, Purhagen, and Wendin (2018) conducted research upon the effect of emulsion intensity on texture properties of full-fat mayonnaise, in which they found no significant difference between samples with regard to color. They suggested that reduced droplet size during homogenization process leads to a whiter final product.

3.5. Density and water activity

Measurements of density and water activity of processed cheese sauces are presented in Table 4. In general, density of processed cheese sauces with OCO was higher than that of samples with AMF. It may be associated with density of different oils/fats. Relative density at 40 °C/20 °C for coconut oils is between 0.908 and 0.921 g/mL (when it started to melt and in this form it has been added to our cheese sauce mix) (Gopala et al., 2009) and for anhydrous milk fat at 50 °C/40 °C, it is 0.893–0.912 g/mL (Fonterra, 2019). Generally, the density of processed cheese sauces with AMF or OCO (> 5 g/100 g) were characterized by an increase ($P < 0.05$) in relation to the content of added whey proteins. The sample with 8 g/100 g WPC80 and OCO was characterized by the highest density (1.1114 g/mL), while with 2, 3, 4 and 5 g/100 g WPC80 content, the smallest (Table 4). In the case of cheese sauces with AMF, the highest density was found in sample with the addition of 7 and 8 g/100 g WPC80 (1.0829 g/mL and 1.0820 g/mL, respectively) and the lowest 2 and 3 g/100 g (1.0396 g/mL and 1.0367 g/mL, respectively). González-Tello, Camacho, Guadix, Luzóno, and González

Table 4
Effect of WPC80 concentration on density and water activity of processed cheese sauces obtained with the basis of AC and OCO or AMF.

Oil/Fat	Content of WPC80 [g/100 g]	Density (g/mL)	Water activity
AC and OCO	2	$1.0571^{c} \pm 0.0036$	$0.996^{bc} \pm 0.004$
	3	$1.0556^{c} \pm 0.0006$	$0.992^{ab} \pm 0.0006$
	4	$1.0503^{bc} \pm 0.0012$	$0.995^{abc} \pm 0.0012$
	5	$1.0497^{bc} \pm 0.0006$	$0.995^{abc} \pm 0.0006$
	6	$1.0750^{de} \pm 0.0006$	$0.994^{abc} \pm 0.0006$
	7	$1.0726^{d} \pm 0.001$	$0.994^{abc} \pm 0.001$
	8	$1.1114^{f} \pm 0.0006$	$0.993^{ab} \pm 0.0005$
AC and AMF	2	$1.0396^{a} \pm 0.0009$	$0.998^{c} \pm 0.0006$
	3	$1.0367^{a} \pm 0.0005$	$0.995^{abc} \pm 0.0006$
	4	$1.0435^{ab} \pm 0.0003$	$0.996^{abc} \pm 0.0006$
	5	$1.0500^{b} \pm 0.0002$	$0.993^{ab} \pm 0.0006$
	6	$1.0537^{c} \pm 0.0005$	$0.994^{abc} \pm 0.001$
	7	$1.0829^{e} \pm 0.0012$	$0.993^{abc} \pm 0.001$
	8	$1.0820^{e} \pm 0.0006$	$0.993^{abc} \pm 0.0005$

Data are presented as means ± SD (standard deviation).
[a-c] Means in the same column with different superscripts are significantly different ($P < 0.05$, Tukey's HSD test).

(2009) in their studies describing different physicochemical properties of whey protein solutions with an average protein content of 77.6 g/100 g, reported that the density increased with the increase of added WPC80 concentration, which is similar to our results.

The water activity of processed cheese sauces with AMF decreased with the increase of WPC80 content (0.998-0.993), but the decrease was not significant ($P > 0.05$). The highest water activity was observed in the sample with 2 g/100 g WPC80 and AMF (0.998) and the lowest after addition of 7 and 8 g/100 g WPC80 and AMF (0.993). In the case of cheese sauces with OCO, the change in WPC80 concentration did not influence their water activity ($P > 0.05$). Coconut oil is characterized by low water activity (Kinderlerer & Clark, 1986) that refers to the amount of unbound water in a substance, which may cause insignificantly important changes in studied sauces. Anhydrous milk fat is produced by removing the water phase from butter (Sichien et al., 2009). Different values of a_w between both types of prepared cheese sauces may be the result of instability of this products, which occurs with a slight delamination on the surface observed during testing process. High water content creates more favorable conditions for the development of mold and fungi, and affects the proliferation of bacteria. According to the FDA, a food product with pH above 4.6 is stable only if its water activity is 0.85 or less. In tested processed cheese sauces, the pH was 5.8, which gives the conditions for the development of undesired microflora at the obtained activity results, in the case of not keeping the product at the refrigeration temperature (Gamay & Schumacher, 1999).

4. Conclusions

Based on the experiment, it can be concluded that the use of coconut oil and anhydrous milk fat as well as different contents of whey proteins affected the structure and appearance of processed cheese sauces. Along with an increase in whey proteins content in the product with the addition of OCO, an increase in hardness (2–7 g/100 g WPC80), adhesiveness (2–7 g/100 g WPC80) and apparent viscosity (2–8 g/100 g WPC80) of cheese sauces was observed. With regard to samples with addition of AMF, hardness and adhesiveness increased in the range of 2–8 g/100 g WPC80. Results obtained from this experiment may suggest that product with the lowest amount of whey protein does not meet the expected requirements. Because of too liquid structure and low viscosity, they do not resemble proper cheese sauces. Color intensity of the evaluated cheese sauces was characterized by various shades of cream. Definitely, color of products with the addition of AMF much more resembled traditional cheese sauces, which may affect the perception of the tested products by consumers. G' and G'' were higher in product with AMF addition. All tested cheese sauces were pseudoplastic substances. Density of processed cheese sauces with OCO was higher than those with AMF. Water activity of tested products with AMF slightly decreased with the increase in WPC80 content, whereas in the case of OCO, it did not change. Based on our results, anhydrous milk fat or coconut oil can be used to obtain processed cheese sauces. From a visual point of view, the sauce with the addition of AMF looked more like cheese sauce and seemed to be more physically and chemically stable than product with the addition of OCO. There is a need for further research on the use of both ingredients in the production of cheese sauces based on acid casein.

CRediT authorship contribution statement

Jagoda O. Szafrańska: Investigation, Writing - original draft, Formal analysis. **Siemowit Muszyński:** Methodology, Investigation, Formal analysis. **Bartosz G. Sołowiej:** Conceptualization, Methodology, Resources, Supervision, Writing - review & editing.

Declaration of competing interest

None.

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Original article

Effect of different fibres on texture, rheological and sensory properties of acid casein processed cheese sauces

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Summary The objective of this study was the evaluation of different fibres (bamboo, acacia, potato or citrus) addition on texture, rheological and sensory properties of acid casein processed cheese sauces. Fibres used in production of sauces had an impact on the texture, viscosity, viscoelastic and sensory properties. The largest increase in viscosity was observed in products with addition of potato fibre, which have good water holding and adsorption capacity. Processed cheese sauce with the addition of citrus fibre was characterised by the highest values in general, and the increase of this feature in the tested samples was regular. Adhesiveness was the highest in products with 1% addition of every fibre. The lowest values of viscosity single shear, G' and G'' moduli, among all tested, had sauces with acacia fibre. Moreover, they had the most thin liquid consistency, which was different from preferred one.

Keywords Acid casein, fibre, processed cheese sauce, rheology, sensory, storage and loss moduli, texture, viscosity, whey protein concentrate.

Introduction

Cheese sauce is widely used as an addition to vegetables, different types of pasta or meat and as a dip for snacks. It is easily available in supermarkets and small stores in various forms, for example as a powder that should be poured with hot water or ready-to-consume product.

The market of cheese sauces has been growing in recent years. Due to the modern lifestyle, innovative solutions related to its production, new substances providing longer shelf life and also more healthier ingredients caused that people reach more often for cheese sauces (Orbis Research, 2017; XYZ Research Report, 2018).

Cheese sauces belong to the group that may contain mixture of ingredients with dairy or non-dairy origin and can be produced using different methods (Saad *et al*., 2015; Salek *et al*., 2019). The most common base in the production of cheese sauces is natural cheese that affects the flavour, texture and mouthfeel of the final product (Banes *et al*., 2014). However, in order to lower the costs and extend the validity period, producers use dehydrated cheese (e.g. cheese powder) as a substitute (da Silva *et al*., 2018). Also, cheese in cheese sauces can be replaced with whey proteins. In last years, this source of protein has become popular and profitable as a value-added nutrition ingredient to food products (Carter & Drake, 2018). Whey proteins not only provide a good structure and texture to final product, but they are the source of bioactive fractions like lactoferrin, immunoglobulin or alpha-lactalbumin (Zapata *et al*., 2017).

As functional additives, hydrocolloids are used: alginates, xanthan gum, carrageenan and guar gum (Hassan *et al*., 2015). Increasingly, dietary fibres can be also used in production. There are very useful nutritional compounds like carbohydrate polymers and polysaccharides (cellulose, hemicellulose, resins, resistant starch, pectic materials or inulin). They are not digested and absorbed in the human small intestine (Gazi *et al*., 2017). In general, the properties of dietary fibres include shortening the time of presence in the digestive tract and increasing the stools bulk, reducing the LDL cholesterol levels in blood and reducing glucose and insulin levels (Phillips, 2013). Products with dietary fibres have better nutritional properties and physiological structure. Many different tests have been conducted to observe and define the effect of adding different fibres on various products, for example, bakery or meat products (Li & Komarek, 2017).

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In our study, we have focused on four different fibres: bamboo, acacia, potato and citrus fibre. Bamboo is a plant that can be recognised as a potential source of antioxidants and bioactive compounds. It is one of the latest additives in food technology that creates new possibilities for designing enriched in fibre products (García-Martínez *et al.*, 2018). Regular consumption of bamboo-based products may reduce the risk of chronic diseases, for example cardiovascular diseases, Parkinson's disease, Alzheimer's disease or cancer (Nirmala *et al.*, 2018). In turn, acacia fibre has proven and recognised prebiotic effects on human health. Because of very low caloric value, it is very good for dietary use and as addition for weight management products. Due to low glycemic index, it is good for people with diabetes. pH of acacia fibre is compatible with milk proteins and it is very suitable for dairy applications, having positive effect on rheological properties of food products (Cherbut *et al.*, 2003; Nakov *et al.*, 2015; Sulieman, 2018). Potato fibre has been in focus of scientists related to food technology for several years, but was never used as a cheese sauce component. It is a co-product of potato starch isolation. It has a chemical composition of fibre components that take part in colonic fermentation (Panasevich *et al.*, 2013). Effects of this fibre on the relative mass and morphology are different between animal species. In rats fed with potato fibre, the mass of the small intestine was increased, but the morphology of duodenum was not affected (Antuszewicz, 2006). On the other hand, in pigs fed with it, a tendency to decrease the mass of duodenum and modified morphology of the small intestine can be observed (Tuśnio *et al.*, 2007; Pastuszewska *et al.*, 2009). Citrus fibre is known for its nutritional and functional properties. Researchers start adding this ingredient to meat products which cause change in rheological properties and hardness (Perez-Santaescolastica *et al.*, 2019). According to our best knowledge, this fibre was never used in cheese sauce formulation. Data confirm that it can reduce the risk of cancer, coronary heart diseases and obesity (Song *et al.*, 2016). Also, it has high water-binding ability and apparent viscosity (Lundberg *et al.*, 2014). We have focused on these four fibres because of their different chemical composition that can affect the texture of prepared processed cheese sauce that was made on the basis of an acid casein and WPC80. In Table 1, we have presented comparison of chemical composition of chosen fibres.

A plant cell consists of few components having an impact on their features. Cellulose is the main element, which is soluble in concentrated acids and insoluble in concentrated alkali. Hemicellulose is a polysaccharide that dissolves in dilute alkali. In turn, lignin is non-carbohydrate cell wall component, whereas pectin is a component of primary cell wall and it is soluble in water and can form gel structure (Dhingra *et al.*, 2012).

The aim of our research was to evaluate the effect of various types of dietary fibre (bamboo, acacia, potato and citrus fibre) which contain different amounts of soluble and insoluble compounds on textural, rheological and sensory properties of processed cheese sauce obtained on the basis of acid casein, whey protein and rapeseed oil. To the best of our knowledge, there is a lack of studies describing the properties of cheese sauces with addition of the above-mentioned fibres. Moreover, there is no research upon the properties and features describing processed cheese sauces based on acid casein, which is very often used in Europe to produce the acid-curd cheese (Sołowiej *et al.*, 2014). Another reason to enrich a product with dietary fibre is creating the health-promoting food that is low in calories and cholesterol. According to current recommendations of Food & Nutrition Board, Institute of Medicine (2001), the average daily requirement of dietary fibre is around 21–25 g per day for women and 30–38 g per day for men. This type of product can be a good substitute for a traditional sauce.

Table 1 Description of average content of selected components in dietary fibres used in research

Fibres used in experiment	Chemical composition
Acacia	Composed of: 39–42% galactose units, 24–27% arabinose units, 12–16% rhamnose units, 15–16 of glucuronic acid units and protein moieties 1.5–2.4% (Atgie, 2018)
Bamboo	Combination of cellulose (73.83%), hemicellulose (12.49%), lignin (10.15%), aqueous extract (3.16%) and pectin (0.37%) (Li *et al.*, 2010)
Citrus	Composed of carbohydrates (about 80% of the total composition), polysaccharides: pectin (42.25%), cellulose (15.95%), hemicellulose is 10.06% (Lundberg *et al.*, 2014)
Potato	Composed of: lignin (less than 5% of total content) and a cellulose (over 35%). The total content of insoluble fraction containing lignin, cellulose and non-cellulosic polysaccharides is around 55% of total weight, while the rest consist to the soluble fraction. The high level of soluble non-cellulosic polysaccharides and also high concentration of galactose acid and uronic acid in this fraction indicates that fibre is rich in pectic substances (Pastuszewska *et al.*, 2009)

Materials and methods

Materials

The following raw materials were used for the production of cheese sauces: whey protein concentrate (WPC80, 76.8% protein) (Milkiland EU Ltd., Warsaw, Poland), acid casein (AC, 92.1% protein) (PPHU Polsero, Sokołów Podlaski, Poland), 100% refined rapeseed oil (RO) (EOL Polska Sp. z o. o., Szamotuły, Poland), bamboo fibre (BF) (Beneo-Orafti SA, Belgium), acacia fibre (AF) (Nexira, Chemin de Croisset, France), potato fibre (PF) (Lyckeby, Starch AB, Fjälkinge, Sweden), citrus fibre (CF) (Roeper GmbH, Hamburg, Germany), disodium phosphate, lactic acid and sodium hydroxide (2 M) (PPH POCH, Gliwice, Poland).

Preparation of processed cheese sauces

AC (6%, *w/w*) and WPC80 (6%, *w/w*) were mixed in distilled water using a magnetic stirrer (Heidolph MR 3002S, Schwabach, Germany) (temp. 21 °C, 300 r.p.m.). Then, 10% of RO (constant value for each sample) followed by 1%, 2%, 3% or 4% of four fibres: BF, AF, PF or CF were added and ingredients were placed in a container and mixed using the H500 homogeniser (Pol-Eko Aparatura, Wodzisław Śląski, Poland) for 2 min at 1 118 ***g***. Disodium phosphate (0.8%, *w/w*) was added, pH was adjusted to 5.8 using lactic acid or sodium hydroxide (2 M), the mixture was immersed in 80 °C water bath and the contents were mixed at 1 118 ***g*** for 10 min according to the method proposed by Sołowiej *et al.* (2015). Finished processed cheese sauces were poured into plastic containers. The samples were stored at room temperature for 30 min, and after that, they were stored overnight at 4 °C. Processed cheese sauces were taken from the refrigerator 1 h before measurement in order to reach the temperature of 21 °C. Due to the consistency of samples, texture and viscosity measurements were carried out in plastic containers (cylindrical, sample size – 40 mm in diameter and 40 mm in height). Every sample was prepared in triplicate.

Profile texture analysis (TPA)

All measurements were performed using the TA-XT2i Texture Analyser (Stable Micro Systems, Godalming, Surrey, UK) according to the protocol described by Sołowiej *et al.* (2015). The processed cheese sauces were twice punctured by a 15 mm diameter probe to achieve 70% deformation. The penetration rate was 1 mm s^{-1}. Processed cheese sauces were evaluated for their hardness and adhesiveness using Texture Expert software. Five measurements were carried out for each of the three replicates.

Viscosity

The apparent viscosity of processed cheese sauces was investigated using a Brookfield DV II + rotational rheometer (Brookfield Engineering Laboratories, Stoughton, MA, USA) equipped with a Helipath Stand and T-bar spindle D. Measurements were carried out at 21 °C with spindle velocity of 0.5 r.p.m. and according to the method described by Sołowiej *et al.* (2015).

Viscoelastic properties

The viscosity single shear rate, as well as storage (G') and loss (G'') moduli of cheese sauces, was measured using Kinexus lab + rheometer (Malvern Panalytical, Cambridge, United Kingdom) using serrated plates (PU40X SW1382 SS and PLS40X S2222 SS, at plate – plate configuration). Measurements were made at 21 °C. The results from measurements were computer-registered in the Kinexus Malvern program – rSpace.

Sensory evaluation of processed cheese sauces

Sensory features of fresh samples of the final product were evaluated by 10 panellists of the staff members of the Faculty of Food Sciences and Biotechnology at the University of Life Sciences in Lublin, Poland, using the scheme of Clark, Costello, Drake & Bodyfelt (2009). The evaluated features of prepared product were as follows: flavour (1–10 points), body and texture (1–5 points), and appearance and colour (1–5 points).

Statistical analysis

Statistical analysis was carried out with a help of the STATISTICA 12.0 PL software (Stat Soft Polska Sp. z o. o., Kraków, Poland). A two-way ANOVA analysis (different fibres and concentrations) was performed, and significant differences between the samples were determined by the Tukey post hoc test at $P < 0.05$.

Results and discussion

Profile texture analysis (TPA)

For most of tested fibres, results described in Table 2 were inconstant. For AF, they ranged between 98 mN for product with 1% addition to 53 mN in sauce with amount equal to 4%. The highest hardness value for product with BF characterised sample with 3% addition of fibre (92 mN) and for PF, it was 2% addition (66 mN) (Table 2). Among the examined fibres, the samples with citrus fibre (CF) was characterised by the highest hardness. Only for this tested product obtained values increase regular. This parameter increased with the amount of added fibre ($P < 0.05$) from 1% (470 mN) to 4% (1030 mN). An increase in hardness may suggest that due to citrus fibre structure that is mostly composed of pectin, cellulose and hemicellulose (Wen *et al*., 1998) and also the same amount of water supplied to a final product, the structure of the sauce became more compact and therefore harder. Other combinations of the base with acid casein and fibre with different contents of water-soluble fractions definitely affected the hardness of the final product, but not as much as sauces with CF. Compositions of individual fibre components (Pastuszewska *et al*., 2009; Li *et al*., 2010) resulted in very diverse values of hardness, but never exceeding the value of 100 mN, even using various fibre concentrations. This information may suggest that other fibres can be used not preferably to modify product hardness, but for example reducing the fat content in product (Brennan & Tudorica, 2008).

In research concerning the effect of inulin on the cheese analogues, Sołowiej *et al*. (2015) observed decrease in product hardness along with an increase in the addition of the tested hydrocolloid. They suggested that protein hydration, and consequently matrix plasticisation, can cause this type of effects. Another example of using the fibre as a fat replacement and textural-affecting addition is incorporated inulin in low-fat yoghurt. Researchers noticed that prepared mixture of raw milk, skim milk and cream with different addition of inulin (0–4%) was not affected by fibre.

Table 2 Effect of different dietary fibres concentration on processed cheese sauces hardness and adhesiveness

	Amount of added fibre (%)	Hardness (mN) ± SD	Adhesiveness (J) ± SD
Acacia fibre (AF)	1	$98^{e} \pm 4$	$292^{f} \pm 6$
	2	$56^{abc} \pm 3$	$155^{b} \pm 4$
	3	$66^{bcd} \pm 1$	$183^{d} \pm 2$
	4	$53^{ab} \pm 2$	$152^{b} \pm 2$
Bamboo fibre (BF)	1	$45^{ab} \pm 4$	$400^{i} \pm 4$
	2	$86^{cde} \pm 2$	$180^{cd} \pm 1$
	3	$92^{de} \pm 2$	$237^{e} \pm 7$
	4	$52^{ab} \pm 1$	$363^{h} \pm 5$
Citrus fibre (CF)	1	$470^{g} \pm 7$	$404^{i} \pm 6$
	2	$880^{h} \pm 1$	$394^{i} \pm 2$
	3	$920^{i} \pm 76$	$331^{g} \pm 9$
	4	$1030^{j} \pm 18$	$231^{e} \pm 3$
Potato fibre (PF)	1	$21^{f} \pm 9$	$273^{f} \pm 7$
	2	$66^{bcd} \pm 4$	$156^{bc} \pm 0.07$
	3	$38^{ab} \pm 2$	$124^{a} \pm 0.2$
	4	$26^{a} \pm 1$	$106^{a} \pm 6$

SD, Standard deviation.
Letters (a-j) indicate significant differences within column at $P < 0.05$.

They suggest that the casein network was not negatively influenced by the inulin and its addition supported the structure of a final product (Guggisberg *et al*., 2009).

The highest level of adherence characterised the sauce with the addition of 1% CF (404 J). Only products with 1% addition of BF (400 J) and 2% CF (394 J) were characterised with results very close to the highest value reported ($P < 0.05$). Adhesiveness of every product with addition of acacia, bamboo and potato fibre at the amounts of 2%, 3% and 4% was lower than 300 J. It may be related to specific fibre features that were used in cheese sauce production, for example, the structure of gel formation by clear exudate from gum acacia (Pinto *et al*., 2001). Also, Sołowiej *et al*. (2015) noticed a decrease in adhesiveness after adding 1%, 2% or 3% inulin to the processed cheese analogues. Decrease of adhesiveness could be also related to the phase separation (Kiziloz *et al*., 2009), which was observed in our study in sauces, especially with addition of AF. A systematic decrease in the values of tested feature has been observed in the case of cheese sauce with the addition of citrus and potato fibre. The cellulose content of added fibres is much lower compared with, for example bamboo fibre (Pastuszewska *et al*., 2009; Lundberg *et al*. 2014; Li *et al*., 2010), which can be correlated with adhesiveness of the final product. As the water-insoluble fraction increases, adhesion of the final product decreases. Both bamboo and citrus fibres in the past were added to dairy products, such as yoghurts and fermented milks (Seçkin & Baladura 2011; Oroian, Paduret & Gutt, 2016; Sendra *et al*., 2008). To the best of our knowledge, despite the idea of adding these fibres to dairy products, there is no research focusing on adhesiveness of processed cheese sauces with addition of fibres.

Viscosity

The reason for the use hydrocolloids in foods is their ability not only to modify the mechanical solid property of a food system, but also flow behaviour of the final product (Saha & Bhattacharya, 2010).

Figure 1 illustrates the viscosity of individual products with addition of various fibres. In general, viscosity of products with PF and AF increased with increasing the fibre concentration, while in sauces with CF, the opposite tendency was noted. Changes in concentration of BF did not influence the final product. The highest viscosity was recorded for 4% PF (13333 Pa·s) and the lowest for 1% BF (113 Pa·s).

Liquid viscosity can be described as a resistance to flow, informally described as 'thickness' (Wanders *et al*., 2014). When molecular weight of fibre and its chain length increases, the viscosity of fibre in a solution usually increases. Soluble fibres characterised

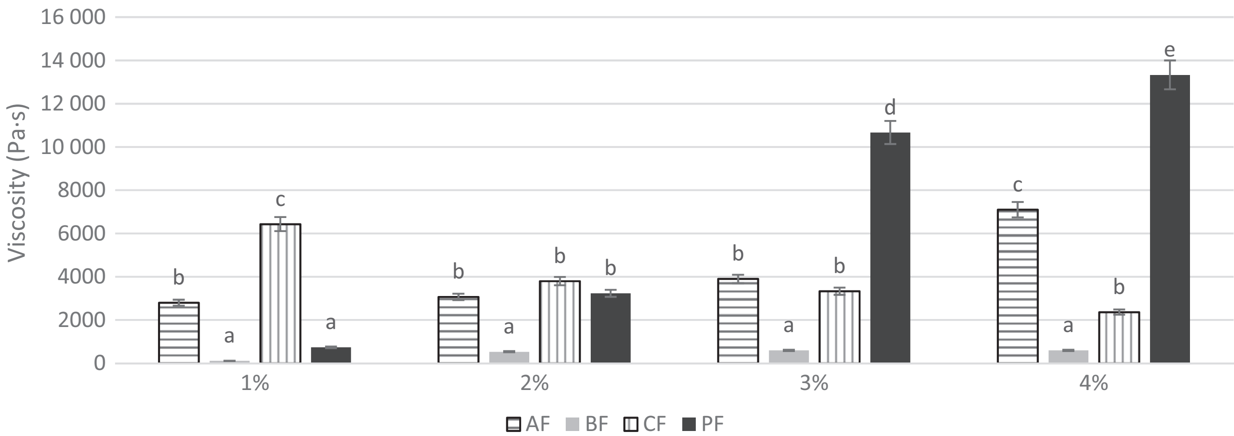

Figure 1 Effect of different dietary fibres concentration on processed cheese sauces viscosity. Letters (a-e) indicate significant differences at $P < 0.05$.

relatively high viscosities in comparison with insoluble fibres (Fabek *et al*., 2014). An example may be long-chain polymers like guar gum that binds large amounts of water and is characterised by high solution viscosity, but highly soluble fibres like arabic gum presents quite low viscosities (Ozyurt & Ötles, 2016). Specific properties of individual hydrocolloids could have an impact on the obtained results. For example, highly branched molecular structure and low molecular weight of arabic gum (acacia gum) can cause the change in viscosity of product and high water solubility properties (Milani & Maleki, 2012). Also, Mothe & Rao (1999) studied rheological behaviour of aqueous dispersions of arabic gum and have found that the infinite shear rate viscosity increased with increasing concentration of gum. In our research, it has also been observed that sauces with acacia fibre had more fluid structure and in some cases delamination of the final product had been observed. Another fibre that is characterised by high water holding capacity is bamboo fibre (Seçkin & Baladura, 2011). In turn, citrus fibres are mostly composed of carbohydrates. Pectin and cellulose are found in the highest amounts in citrus fibre. Because of the acidic nature of the pectin components, it is used not only in food applications for its apparent viscosity and also gelling properties (Willats *et al*., 2006; Lundberg *et al*., 2014).

Viscoelastic properties

Figure 2a–d show viscosity single shear rate for each processed cheese sauce with different concentrations of fibre.

Viscosity shear rate is important factor, because it may affects the viscosity, process ability and applicability of various materials. In every example, tested products are shear thinning. Shear thinning fluids are also known as pseudo-plastics, and they often occur in industrial and biological processes (Alves, 2019).

From Fig. 2, it can be observed that the use of different fibres in formulating processed cheese sauces had impact on the viscosity of the resultant products. The flow behaviour in all viscosity versus shear rate charts for tested sauces show that the viscosity was decreased during time (Fig. 2a–d). The highest values for processed cheese sauce with 1% addition of fibres described the product with PF during the first 13 s then during time, the sample with CF obtained higher values (Fig. 2a). For all products with 2% and 3% addition, results show that viscosity of sample with BF was higher than that of the others. The lowest values occurred for AF and CF samples (Fig. 2b–c). And for the 4% addition of fibres, the highest values are found for processed cheese sauces with PF then BF, AF and CF. However, the viscosity drop for sauce with addition of 4% AF (Fig. 2d) was not continuous. A small increase was observed at intermediate shear rates. Lower viscosity value in processed cheese sauce formula with AF could be due to the type and nature of added fibre. Structure of fibre may has been affected during homogenisation and therefore has been given a lower viscosity. We also have observed that added AF caused foaming of the final product. This may be due to the fact that AF contains about 95% of soluble fibres (Mohamed *et al*., 2015). In each of the studied cases, the shear thinning was observed from 0 to 5 s. At intermediate shear rates from 5 to 15 s viscosity decreased and then became almost constant.

As far as we know, there is no research about viscoelastic properties of cheese sauces with addition of any dietary fibres, but researchers have tested viscoelastic properties of pectin gels enriched with dietary

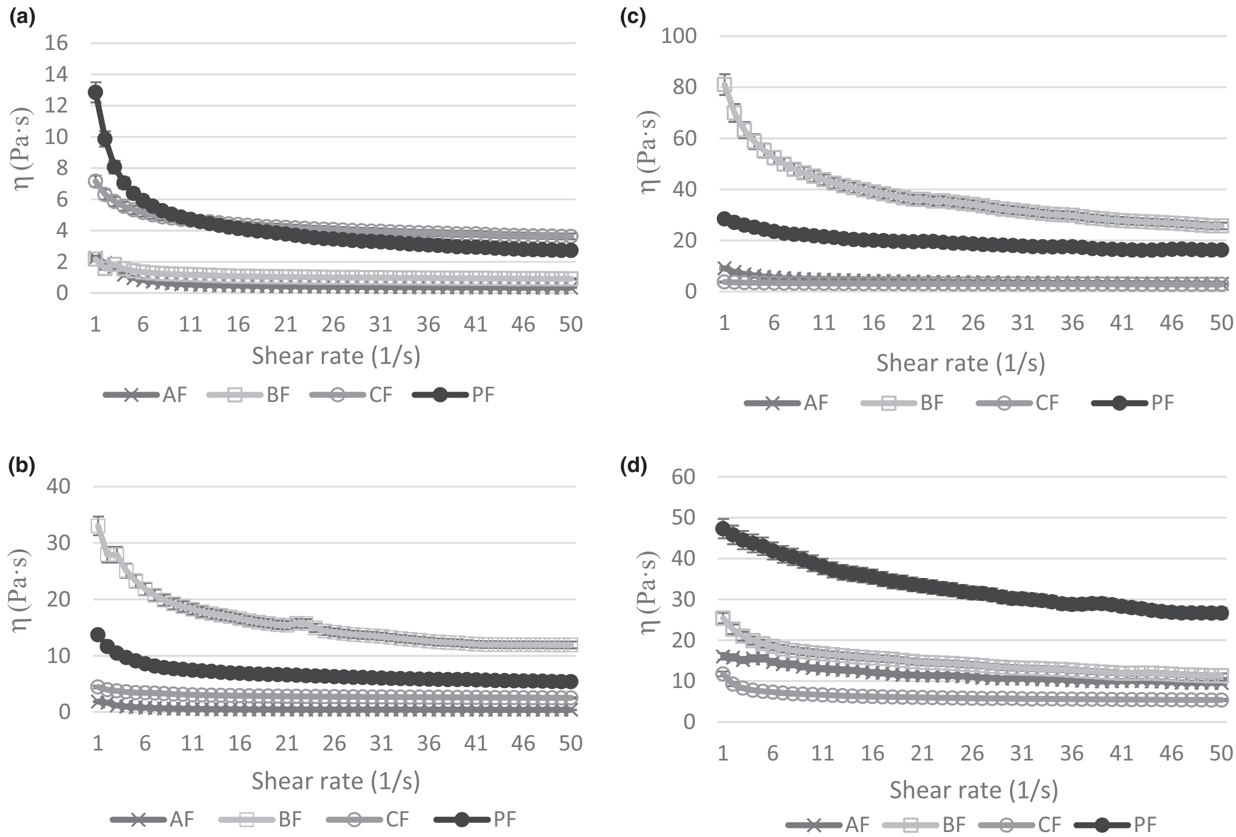

Figure 2 Viscosity as a function of shear rate for processed cheese sauces with different dietary fibres concentration (x – AF – acacia fibre; □ BF – bamboo fibre; ○ CF – citrus fibre; ● PF – potato fibre) (a) 1% AF, BF, CF or PF (b) 2% AF, BF, CF or PF (c) 3% AF, BF, CF or PF (d) 4% AF, BF, CF or PF.

fibres to obtain healthy confectionery jams. They discovered that jams with addition of bamboo fibre and low pectin content can form the weakest gels (Figueroa & Genovese, 2018). In our experiments, from all used fibres, bamboo had the lowest amount of pectin and the highest values of viscosity as a function of shear rate with addition of 2 and 3%, similar to sauce with potato fibre (with addition of 4%).

In Table 3, the effect of dietary fibres concentration on processed cheese sauces storage (G') and loss (G'') moduli was reported. Because cheese sauce structure can be described as gel-like, we can measure both parameters. Storage modulus (G') represents energy that is stored elastically in the structure of gel during temporal application of stress and G'' reflects the flow of a material while it is deformed (Saha & Bhattacharya, 2010).

In tested products with the addition of BF and PF, the value of G' and G'' moduli increased along with the increase in fibre amount (1–4%), which proves the strengthening of the gel structure of tested products. In sample with the addition of AF, there was no uniform increase in the described features. Values of moduli G' and G'' increased in the product with AF (1–2%), and with larger amounts of fibre, they were decreasing (3–4%). In all tested sauces, the values of storage (G') modulus were always higher than the loss (G'') modulus. It means that processed cheese sauces exhibit elastic (gel) properties during the whole measurement. Also, we did not observed relationship between hardness and storage modulus (G'). Processed cheese sauces with CF had the highest values of hardness, but the lowest of G'. In each tested product, samples with 1% addition of fibres had the lowest G' and G'' values, indicating that gel structure of the processed cheese sauces had been weakened and formed less elastic system. The highest values from Table 3 are consistent with observations upon our product and point to the solidification of the cheese sauce matrix. In product with 3% and 4% AF, values of G' and G'' began to decrease, which can be caused by softening of the cheese sauce matrix, despite that every tested

Table 3 Effect of different dietary fibres concentration on processed cheese sauces storage (*G*′) and loss (*G*″) moduli

	Amount of added fibre (%)	*G*′(Pa) ± SD	*G*″ (Pa) ± SD
Acacia fibre (AF)	1	$406^{e} \pm 2$	$146^{d} \pm 3$
	2	$914^{h} \pm 39$	$727^{i} \pm 9$
	3	$786^{g} \pm 2$	$246^{f} \pm 3$
	4	$345.54^{d} \pm 1$	$119^{cd} \pm 2$
Bamboo fibre (BF)	1	$681^{f} \pm 3$	$208^{e} \pm 1$
	2	$905^{h} \pm 3$	$310^{g} \pm 3$
	3	$2640^{j} \pm 48$	$1073^{j} \pm 6$
	4	$4282^{l} \pm 166$	$1608^{n} \pm 17$
Citrus fibre (CF)	1	$248^{c} \pm 1$	$87^{bc} \pm 1$
	2	$210^{a} \pm 0.4$	$53^{a} \pm 1$
	3	$257^{c} \pm 1$	$62^{b} \pm 1$
	4	$225^{b} \pm 1$	$57^{ab} \pm 0.5$
Potato fibre (PF)	1	$1778^{i} \pm 5$	$501^{h} \pm 5$
	2	$3858^{k} \pm 23$	$1300^{k} \pm 10$
	3	$4741^{m} \pm 50$	$14184^{l} \pm 14$
	4	$5993^{n} \pm 32$	$1519^{m} \pm 5$

Letters (a-n) indicate significant differences within column at $P < 0.05$.

product displayed a weak gel properties until the end of experiment ($G' > G''$). We have noticed that G' values were higher in products with bamboo and potato fibre. This could be due to the fact that both fibres have lower amount of water-soluble fractions. It was observed that in product with higher pectin content gel network is thicker, has stronger pectin network and a firmer gel structure (Löfgren, Walkenström & Hermansson, 2002). We suspect that the insoluble fraction of the fibre used in our research acted as a filler of the gel, causing the reinforcement of the structure. Figueroa & Genovese (2018) have noticed similar relationships during their research.

Sensory evaluation of processed cheese sauces

The sensory characteristics of processed cheese sauce are the result of the source of protein, used fat, emulsifying salts and dietary fibre added to basic formula. Sensory scores for each of the sauces were shown in Fig. 3. All tested properties of processed cheese sauces were evaluated after trying the fresh products. Not all samples were well accepted by the panellists, and differences between the products were noticeable. Cheese sauces with addition of acacia fibre (AF) had the lowest scores from all tested samples for all tested features (flavour: 4.1–5.1; body and texture: 4.7–4.9; and appearance and colour: 4.7–4.9). This was connected with their semi-liquid consistency. Opinions of testers confirmed our results regarding uneven product texture. In the group with the addition of acacia fibre, products with 1% addition were the best rated. Group of products with BF was characterised by the highest scores with 2 and 3% addition. Sauce with BF was described as too bright, even white. This description given by the panellists was strongly connected with colour of the fibre used to prepare sauces. Bamboo

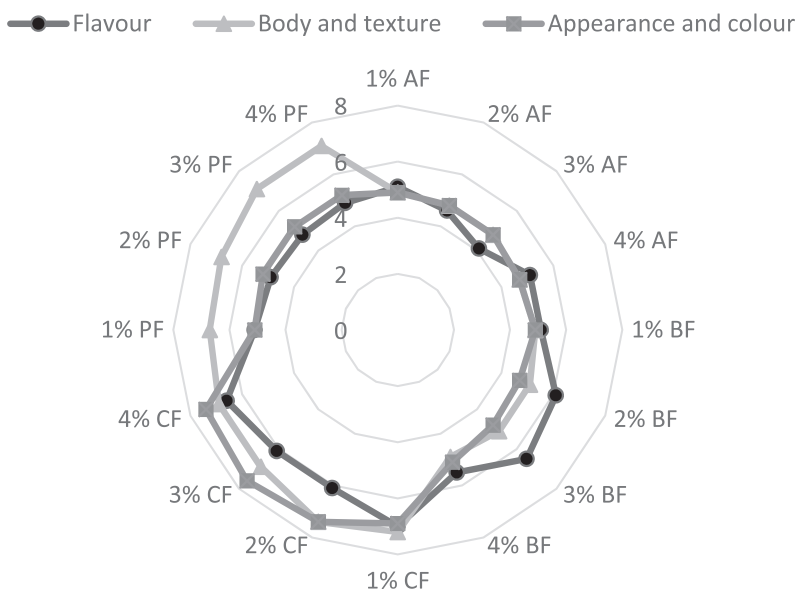

Figure 3 Sensory evaluation of processed cheese sauces obtained on the basis of acid casein and different dietary fibres (1–4%).

AF- acacia fibre; BF- bamboo fibre; CF- citrus fibre; PF- potato fibre.

fibre is white and final product had the same tone. Researchers added bamboo fibre to yoghurt and drew the same conclusion (Seçkin & Baladura, 2011). Of all tested sauces, the products with the addition of CF had the highest scores in every described category. The sauce with the addition of PF, due to particles insoluble in the product, despite the good consistency, had not been well evaluated in terms of its appearance. In addition, its colour also had the lowest rate. Potato fibre, because of its appearance and colour, was most often added to meat (Mehta, Ahlawat, Sharma & Dabur, 2013) or bread (Kaack, Pedersen, Laerke & Meyer, 2006), where these features do not change the appearance of the product. Also, from all tested samples, the highest score describing the colour was received by sauce with addition of CF. The panellists described this colour that is the closest to cheese sauces from all tested samples. The highest scores of overall value of sensory evaluation were received by cheese sauce with BF and CF. With regard to the flavour, processed cheese sauces with AF and PF were characterised by lower scores.

Conclusions

Textural and rheological properties of processed cheese sauces were influenced by the addition of dietary fibres. For example, CF increased the hardness of a final product. At the same time, viscosity of this sauce decreased. In turn, hardness of the sauce with PF was decreasing with increase in viscosity. Also, this product was characterised by the highest viscosity. Adhesiveness was the highest in all products with 1% of fibre. In all tested sauces, the values of storage (G') modulus were always higher than the loss (G'') moduluspuro. All viscosity versus shear rate charts for tested products showed high values at low shear rates, followed by viscosity decreases when the shear rate increased. In every example, tested products were shear thinning. However, the viscosity drop for the sauce with addition of 4% AF was not continuous. From test describing sensory aspect of produced sauces, the highest scores received product with addition of citrus and bamboo fibre.

The observed improvement in textural properties manifested by lower hardness and adhesiveness in most samples suggested that potential fibres can be used as an addition to processed cheese sauces based on acid casein and whey protein concentrate. The conducted research is the basis for further experiments related to the use of dietary fibres in dairy products, especially cheese sauces.

Conflict of interest

There is no conflict of interest between the authors.

Ethical guidelines

Ethics approval was not required for this research.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Article

The Influence of Dietary Fibers on Physicochemical Properties of Acid Casein Processed Cheese Sauces Obtained with Whey Proteins and Coconut Oil or Anhydrous Milk Fat

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Abstract: This study aimed to evaluate different fibers (acacia, bamboo, citrus or potato) on texture, rheological properties, color, density, and water activity of processed cheese sauces (PCS) based on acid casein, WPC80 and anhydrous milk fat or organic coconut oil. The interaction between the type of oil/fat, the fiber type and the fiber content was significant regarding almost all parameters studied. The computer vision system (CVS) showed that color changes of sauces could be noticeable by consumers. The main factor influencing the change in all products' hardness was not fat/oil, but added fibers and their concentrations. The highest increase in hardness, adhesiveness and viscosity was observed in products with potato fiber. The value of storage modulus (G′) was higher than the loss modulus (G″) and tan (δ) < 1 for all samples. Different fibers and their amounts did not influence the water activity of cheese sauces obtained with organic coconut oil (OCO) or anhydrous milk fat (AMF).

Keywords: polysaccharide; computer vision system; texture; viscoelasticity; density; water activity

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1. Introduction

At the end of the year 2018, Innova Market Insights, a company tracking new food and beverage products on present and future trends, published a forecast for 2019, "Top 10 Trends for 2019". One of the presented vital points was "A fresh look at fiber". Analytics suggested that consumers growing interest in fiber will cause the manufacturing of new fiber applications in the next few years [1]. Consumers have started to pay attention to the composition of food products they buy and are increasingly willing to reach for products with higher dietary fiber content. According to several systematic reviews and meta-analyses, clinical research and observational studies performed for almost 40 years show the advantages of having a healthy diet by consuming at least 25 g to 29 g or more of dietary fiber a day [2]. Fibers can also be incorporated into dairy products to meet such health requirements. This type of innovation can increase fiber-rich foods availability and people's understanding of their advantages to their health.

Most of the dairy-based foods are considered to belong to the high-moisture group of products. For this type of application, soluble fibers generally work excellently. Processed cheese sauce is one of the food products a part of the described group with high water activity. Because the formulations do not have strict standards or legal definitions, they may be made up of a number of different dairy or non-dairy ingredients, including fiber [3]. Commercial cheese sauces are a mixture of various ingredients. The typical base of cheese sauces includes cheese solids, different flavor systems and fat sources (including animal fat: butter, buttermilk and lard or/and vegetable oils: palm, soy, or canola). In addition, texture additives and fillers [4]. For the processed cheese sauce production described and tested in this article, semi-finished products with additional health-promoting properties were used. The main ingredient of the described formula is whey protein concentrate (WPC80). It is a rich source of amino acids and contains a high concentration of essential amino acids [5]. Additionally, another ingredient of the described formula, acid casein, has water-binding properties [6]. Coconut oil (OCO) contains medium-chain fatty acids, which correspond to 64% of the total fat. According to the findings, medium-chain saturated oil may help reduce intermuscular and abdominal fat more effectively than long-chain unsaturated oil [7]. It was found that some nutritional benefits of OCO were due to its chemical composition. Numerous studies have been conducted to describe the possible health-promoting effects of coconut oil, e.g., a positive cardioprotective/hypocholesterolemic effect, anticancer, antidiabetic or hepatoprotective activity [8]. In turn, tests conducted to determine the properties of anhydrous milk fat (AMF) show that consumption of AMF causes a decrease in the concentration of low-density lipoprotein (LDL) and decreased amount of liver total cholesterol and cholesterol esters [9]. Traditional cheese sauces can contain around 3% of emulsifying salts, which are commonly considered harmful to health in higher doses. Sołowiej et al. [10] reported that replacement of typical emulsifying salts (phosphates) could be possible due to the use of whey proteins [10]. In the designed product formulation, the amount of emulsifying salts has been reduced to just 0.8%, due to WPC80.

Another innovation in the presented formula is the addition of dietary fibers. They can play an important role in preventing many chronic diseases, such as diabetes, obesity, atherosclerosis or heart diseases [11].

Dietary fiber is a part of plant material which includes cellulose, noncellulosic polysaccharides (hemicellulose, pectic substances, gums, mucilages) and also a non-carbohydrate component: lignin. In our study, four types of dietary fiber (acacia, bamboo, citrus and potato fiber) were used. Dietary fiber is easy to incorporate, stabilizes the dairy product and maintains its creamy and smooth final texture [12]. The first attempt to obtain a new type of processed cheese sauce based on rapeseed oil with the addition of fibers was described in 2020. The received textural and rheological results provided impressive knowledge about improvements in the properties mentioned above. Most prepared samples had lower hardness. This research indicated that fibers can be potentially used in processed cheese sauces [13]. In this article, we expanded the research scope with additional analyses of color using a new type of method for cheese sauces color assessment—the computer vision system (CVS), measurements of the tan (δ), yield stress, water activity and density of tested cheese sauces. Moreover, to the authors' knowledge, there is no research concerning the effect of dietary fibers on acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat, thus, to obtain PCS in this research, the sources mentioned above were used.

Trans and saturated fatty acids are related to the possibility of developing cardiovascular diseases. However, intake of anhydrous milk fat (AMF) is correlated with health-promoting effects [9]. It has a minimum of 99.8% milk fat and no more than 0.1% moisture [14]. Due to certain medium-chain fatty acids, organic coconut oil (OCO) is perceived as healthy because of its capability to be quickly absorbed by the digestive system, causing satiety and preventing fat storage [15]. Additionally, the whey protein concentrate (WPC80) used to prepare our product also has health-promoting properties [16]. It is characterized by antibacterial, antitumor [17] and antifungal properties [18]. Acacia fiber is an emulsifier with low-viscosity and high solubility in cold aqueous solutions [19]. Bamboo fiber contains over 70% cellulose (insoluble), 10% lignin (insoluble) and only 12% hemicellulose (soluble) [20]. The majority of the composition of citrus fiber is pectin (around 40%), hemicellulose (10%) and cellulose (15%) [21]. Commercial potato fiber is composed of lignin (2%), cellulose (over 23%), pectin and hemicellulose (45%) and total content of non-starch polysaccharides (59%, of which 23% is soluble and 32% is insoluble) [22].

Thus, this study aimed to test the influence of different dietary fibers (acacia, bamboo, citrus or potato) on rheological and texture properties, color, density and processed cheese sauces' water activity. Our experiment focused on obtaining processed cheese sauce based on whey protein concentrate (WPC80) and acid casein with the addition of various dietary fibers that previously have never been used in this type of product, which was obtained with coconut oil or anhydrous milk fat.

2. Materials and Methods

2.1. Materials

In the production of processed cheese sauces (PCS), the following raw materials were used: acid casein (AC, 92.1% proteins, PPHU Polsero, Sokołów Podlaski, Poland), whey protein concentrate (WPC80, 76.8% proteins, Milkiland EU Ltd., Warsaw, Poland), organic coconut oil (OCO, Bio Planete, Lommatzsch, Germany), anhydrous milk fat (AMF, 99.8% fat content, Mlekovita, Wysokie Mazowieckie, Poland), acacia fiber (AF) (Nexira, Chemin de Croisset, France), bamboo fiber (BF) (Beneo-Orafti SA, Belgium, citrus fiber (CF) (Roeper GmbH, Hamburg, Germany), potato fiber (PF) (Lyckeby, Starch AB, Fjälkinge, Sweden), lactic acid, disodium phosphate and sodium hydroxide (PPH POCH, Gliwice, Poland).

A series of samples of processed cheese sauces were prepared to carry out a series of individual tests described in the Material and Methods subsection. In general, 32 samples of tested PCS were prepared in the appropriate number of repetitions needed to perform the tests with the methods described below.

2.2. Determination of Proteins

According to AOAC (Association of Official Analytical Chemists) requirements, the protein content of acid casein (92.1%) and whey protein concentrate (76.8%) was determined by measuring the nitrogen using Kjeldahl methods and calculating protein as N·6.38 [23].

2.3. Preparation of Processed Cheese Sauces

WPC80 (6%, *w*/*w*) and AC (6%, *w*/*w*) were mixed in distilled water using a magnetic stirrer (Heidolph MR 3002S, Schwabach, Germany) (300 rpm, temp. 21 °C). Then, 10% of OCO or AMF (constant value for each sample, melted in 45 °C), followed by 1, 2, 3 or 4% of four fibers: AF, BF, CF or PF were added and constituents were placed in a vessel and mixed using the H500 homogenizer (Pol-Eko Aparatura, Wodzisław Śląski, Poland) for 2 min at 10,000 rpm. Disodium phosphate (0.8%, *w*/*w*) was added, pH was adjusted to 5.8 using sodium hydroxide or lactic acid (2 M), the mixture was immersed in 80 °C water bath and the ingredients were mixed at 10,000 rpm for 10 min according to Szafrańska et al. [24].

2.4. Penetration Test

The TA-XT2i Texture Analyzer (Stable Micro Systems, Godalming, Surrey, UK) was used to perform all measurements, which followed the protocol defined by Szafrańska et al. [24]. A 15 mm diameter cylindrical probe was used to penetrate processed cheese sauces to a depth of 28 mm. The rate of penetration was 1 mm/s. Texture Expert software was used to determine the hardness and adhesiveness of processed cheese sauces. Five measurements were taken for each of the three replicates.

2.5. Viscosity

A Brookfield DV II+ rotational rheometer (Brookfield Engineering Laboratories, Stoughton, MA, USA) fitted with a Helipath Stand and T-bar spindle D was used to examine the apparent viscosity of processed cheese sauces. According to the method of Szafrańska et al. [24], three measurements were carried out at 21 °C with a spindle velocity of 0.5 rpm.

2.6. Viscoelastic Properties

According to Szafrańska et al. [24], storage (G′) and loss (G′′) moduli, tan (δ) and yield stress of cheese sauces were measured using serrated plates (PU40X SW1382 SS and PLS40X S2222 SS, at the plate—plate configuration) on a Kinexus lab + rheometer (Malvern

Panalytical, Cambridge, UK). The Kinexus Malvern software—rSpace—was used to record the results of the measurements (three repetitions), which were made at 21 °C.

2.7. Colorimetric Measurements—Computer Vision System (CVS)

Colorimetric measurements (three repetitions) of obtained processed cheese sauce (PCS) was described with parameters L* (0–100, estimation of lightness), a* (red-green) and b* (yellow-blue) using a computer vision system (CVS) with the use of Sony Alpha DSLR-A200 digital camera (10.2 Megapixel CCD sensor) according to the method described by Tomasevic et al. [25]. According to the National Bureau of Standard reference scale, the notable differences could be described, which identified that such changes are noticeable to the human eye.

The total color difference was calculated using the formula:

$$\Delta E = \sqrt{(a_1 - a_2)^2 + (b_1 - b_2)^2 + (L_1 - L_2)^2} \quad (1)$$

The ΔE* values were converted into National Bureau of Standards (NBS) units by the equation [26]:

$$\text{NBS units} = \Delta E \times 0.92 \quad (2)$$

2.8. Water Activity

The Aqua Lab 3 TE water activity meter (Decagon Devices Inc., Pullman, WA, USA) was used to measure water activity (aw) with a precision of +/− 0.001 of an a_w unit. The Rotronic humidity standard was used to calibrate the apparatus prior to measurement (95% HR). According to Szafrańska et al. [24], measurements were carried out in five repetitions at a temperature of 22 °C. Two outliers were reported as defective in each sample and were removed from further analysis.

2.9. Density

At a temperature of 22 °C, a gas pycnometer (AccuPyc 1330; Micromeritics, Norcross, GA, USA) was used to determine density [24]. The analysis was performed in three repetitions of each tested product.

2.10. Statistical Analysis

The data were analyzed using a 2 × 4 × 4 factorial arrangement with a type of oil/fat (AFM or OCO), fiber type (AF, BF, CF, PF) and fiber concentration (1%, 2%, 3%, 4%) as the factors and their interactions (a three-way ANOVA). The Shapiro–Wilk test was applied to verify which variables had a normal distribution; the Levene test examined homogeneity of variances. As all the data show normal distribution, treatment means were separated using the Duncan's test when significant differences were found among treatments. For all tests, a p-value < 0.05 and a confidence interval of 95% were established. PCA (principal component analysis) was also applied to the average values of physical properties (hardness, adhesiveness, viscosity, yield stress, G', G'', tan (δ)) of all samples studied. The Kaiser–Meyer–Olkin measure (KMO) and Bartlett test of sphericity were used to determine the PCA's significance. All calculations were carried out with Statistica software (v. 13.3, TIBCO Soft-ware Inc., Palo Alto, CA, USA).

3. Results and Discussion

To comparatively analyze the influence of the type of oil/fat (AFM or OCO), fiber type (AF, BF, CF, PF) and fiber concentration (1%, 2%, 3%, 4%), a three-factor ANOVA with interactions was performed (Table 1). The outcomes reported that the interaction between the type of fat/oil, the fiber type and the fiber content was also significant for almost all parameters studied. It means that the effect of the type of fat/oil on studied parameters depended on the fiber type and its concentration in the system. Only for water activity, the effect of the type of fat/oil depended only on fiber content, irrespective of its type.

Table 1. Effects of the type of fat/oil, type of fiber and fiber concentration on physical parameters of acid casein processed cheese sauces (three-way ANOVA, F-ratio and *p*-values).

Dependent Variable	Item	Main Factor			Interactions			
		A: Fat	B: Fiber Type	C: Fiber Content	A × B	A × C	B × C	A × B × C
G′	F stat	683	1502	523	622	1281	825	1067
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
G″	F stat	788	1623	623	827	1212	801	1142
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tan (δ)	F stat	170	273	74	296	90	10	166
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Yield stress	F stat	55,466	3592	30,609	837	13,302	929	2699
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hardness	F stat	529	92	330	105	149	39	46
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Adhesiveness	F stat	744	95	421	270	444	128	113
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Viscosity	F stat	919	9	429	647	572	161	69
	p-value	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	<0.001
L*	F stat	241	65	59	119	7	36	14
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
a*	F stat	144	96	17	95	17	7	20
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
b*	F stat	240	388	31	270	32	71	51
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chroma	F stat	251	381	22	252	29	65	47
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hue	F stat	18	36	78	115	22	39	24
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Density	F stat	173	75	161	110	24	88	15
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Water activity	F stat	5	0	2	2	2	0	2
	p-value	0.003	0.834	0.075	0.185	0.040	0.829	0.060

3.1. Penetration Test

The effect of different fiber types and concentration on PCS texture attributives obtained-based on acid casein with AMF, or OCO is presented in Figures 1 and 2. Generally, the final products' hardness depended on the amount and type of added fiber and fat/oil type. The hardness of PCS with the addition of AF and BF decreased along with an increased amount of fiber ($p < 0.05$). In both formulas with OCO and AMF, the same tendency was observed. The greatest hardness characterized PCS with 4% PF + AMF (0.863 N), while the products with the lowest hardness were obtained with AMF/OCO with 3 and 4% addition of AF/BF. In addition, 1% PF + OCO/AMF ($p < 0.05$) (Figure 1).

Understanding the structure of fibers and fat/oil used in research is important to describe better and understand the differences between hardness values of final products. The primary classification, commonly used, describes fiber as a plant-based nutrient containing soluble and insoluble parts [27]. Both types of dietary fibers have similar physical properties, including the ability to bind water [28]. However, polysaccharides classified as capable of dissolving in water can be quite variable in their actual solubility [29]. The part that is considered soluble components of DF are hemicelluloses, pectins, gums and mucilage. Lignin, cellulose and resistant starch are described as insoluble fractions. Many of the mentioned polymer types can be classified as soluble or insoluble depending on the plant source and degree of post-harvest processing [30].

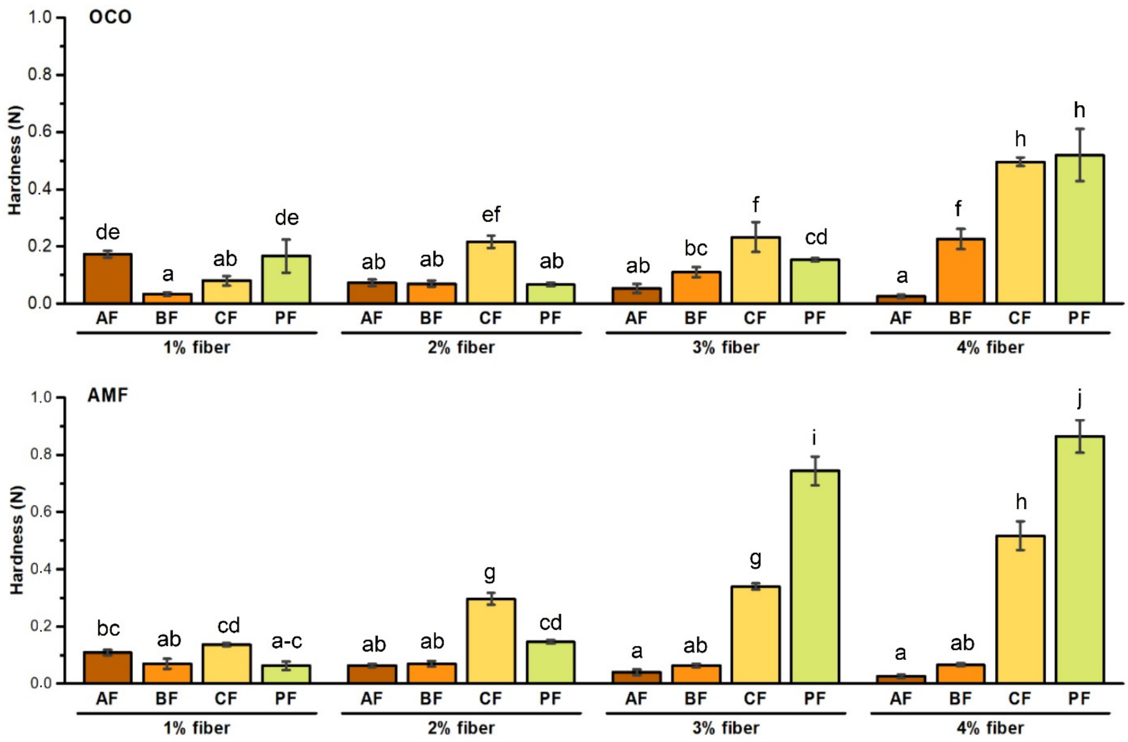

Figure 1. Effect of fiber type and concentration on hardness of PCS (processed cheese sauces) obtained on the basis of AC (acid casein) and WPC80 (whey protein concentrate) with OCO (organic coconut oil) or AMF (anhydrous milk fat). Letters (a–j) indicate significant differences at $p < 0.05$.

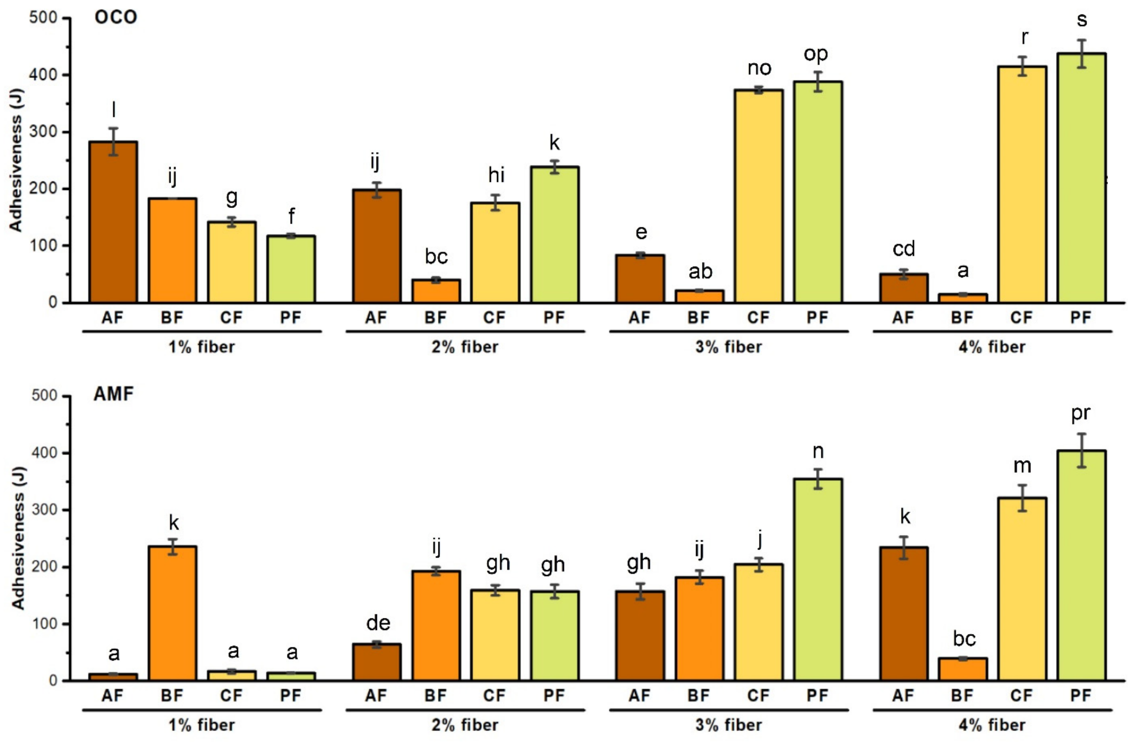

Figure 2. Effect of fiber type and concentration on adhesiveness of PCS (processed cheese sauces) obtained on the basis of AC (acid casein) and WPC80 (whey protein concentrate) with OCO (organic coconut oil) or AMF (anhydrous milk fat). Letters (a–p,r,s) indicate significant differences at $p < 0.05$.

Results suggested that the main factor influencing the change in all products' hardness was not fat/oil, but added fibers and their concentrations. In each sample, hardness was increased in sauces with addition of CF + OCO (from 0.08 to 0.5 N) CF + AMF (from 0.1 to 0.5 N) and PF + OCO (from 0.07 to 0.5 N) and PF + AMF (from 0.06 to 0.9 N). In each case, about half of the fiber composition contains soluble fractions. Due to better binding capacity with water, the final processed sauce structure became more compact, thus, harder. In 2020, we conducted a series of experiments examining the effect of rapeseed oil and various fibers on the cheese sauce structure. We observed an increase in hardness values in products with the addition of citrus fiber, which is similar to the described results in products with CF + OCO/AMF [13]. We did not notice an increase in the value mentioned above in sauces with potato fiber addition, suggesting that oil/fat addition has a great impact on product hardness. To the best of our knowledge, no research data concern dietary fibers' effect on PCS-based on acid casein and coconut oil or milk fat. Akalın et al. [31] tested the structure of ice creams with the addition of dietary fiber. They added different fibers (apple, orange, oat, bamboo and wheat) and noticed that each product was characterized with good hardness, except for the product supplemented with bamboo fiber. They also noticed that the highest hardness values were observed in ice cream with orange fiber [31]. In both examples, the gelling properties and water-holding capacity provided a better and more compact composition of final products. There is no study describing incorporating potato fiber to different dairy products, but few attempts to test it in other food products—bread enriched with potato fiber. Kaack et al. [32] noticed the increase in hardness of bread, which can be connected with protein hydration and, consequently, matrix plasticization [32].

Among all examined samples, the highest level of adhesiveness characterized the sauce with the addition of 4% PF + OCO (437 J). PCS with 4% PF + AMF (404 J) and 4% CF + OCO (415 J) were characterized with results very close to the highest value noted ($p < 0.05$) (Figure 2). The adhesiveness of products with AF + OCO and BF + OCO/AMF was systematically decreased as the added fiber percentage increased. In each case, the value of adhesiveness was lower than 300 J. Sanchez et al. [33] analyzing the available literature on the properties and features of acacia gum noticed that as the concentration of acacia gum (acacia fiber) in dispersions increased from 3% to 10%, the amount of water bound decreased from 1.2 g to 0.6 g/g of gum [33]. Our findings show that as the concentration of these fiber macromolecules increased, some self-association (i.e., aggregation) occurred. It leads to decreased water accessibility and bound water release from acacia fiber macromolecules during the aggregation process. The noticeable phase separation observed in our study, particularly with the addition of AF, could also be linked with decreased adhesiveness. This decrease in products' adhesiveness and a growing amount of added fibers has also been noticed in sauce with bamboo fiber. Differences between these two products were observed between samples with different oil/fat. Product with BF + OCO presented the same results as with the addition of AMF, which was not noticed in PCS with AF. In addition, in our research from 2020 on PCS with the addition of DF and rapeseed oil, we noticed a different tendency of adhesiveness between the different percentages of added fibers. In products with CF and PF, the value systematically decreased along with an increase in added fibers, suggesting that oil/fat added to cheese sauce was the main factor influencing its properties [13]. Animal fat composition depends on many factors, including diet and seasoning. Vegetable fats like coconut oil are less variable. Anhydrous milk fat is a mixture of triacylglycerols, contains at least 60 different fatty acids and has unique thermal and chemical properties [34]. The physical properties of fat that influence food features containing them are mainly concerned with the phase changes that occur during these state transitions, such as solid to solid, liquid to solid or solid to liquid [35]. Milk fat has its source in the globule, predominantly in the form of spherical globules enclosed by a membrane made up of protein and phospholipid. Anhydrous milk fat is the final product after the membrane content has been almost completely eliminated [36]. AMF contains a small amount of phospholipids (around 0.01%) [37]. This disproportion may be related to how the adhesiveness changes in individual sauces. Rich fat globule membrane that is removed from AMF has a great impact on adhesiveness. Le et al. [38] prepared yogurts enriched with milk fat globules and reported increased water-holding capacity and stronger adhesiveness [38]. Despite the idea of incorporating fibers including bamboo [31], acacia [39] or citrus [40] to dairy products like ice-cream, mozzarella cheese or yogurts, to the best of our knowledge, there is lack of research focusing on parameters including adhesiveness of PCS with addition of fibers.

3.2. Viscosity

Viscosity parameter relating to dietary fiber as a component of food product, when mixed with fluids, refers to the ability of some polysaccharides to thicken or form gels as a result of physical entanglements among the polysaccharide constituents within the prepared fluid or solution [41]. Figure 3 illustrates the viscosity of individual products based on AC and WPC80 with OCO or AMF and the addition of the various amounts of different fibers. Generally, the viscosity of PF + OCO/AMF and CF + OCO/AMF cheese sauces increased along with higher fiber concentration. Simultaneously, in sample with BF + OCO/AMF, the inverse trend was observed, suggesting that the added fiber's structure has exerted the opposite effect on the final product completely. In sauces with AF + OCO/AMF, the viscosity value remained at a similar level. The viscosity of 4% PF + AMF was the highest (35,400 Pa·s).

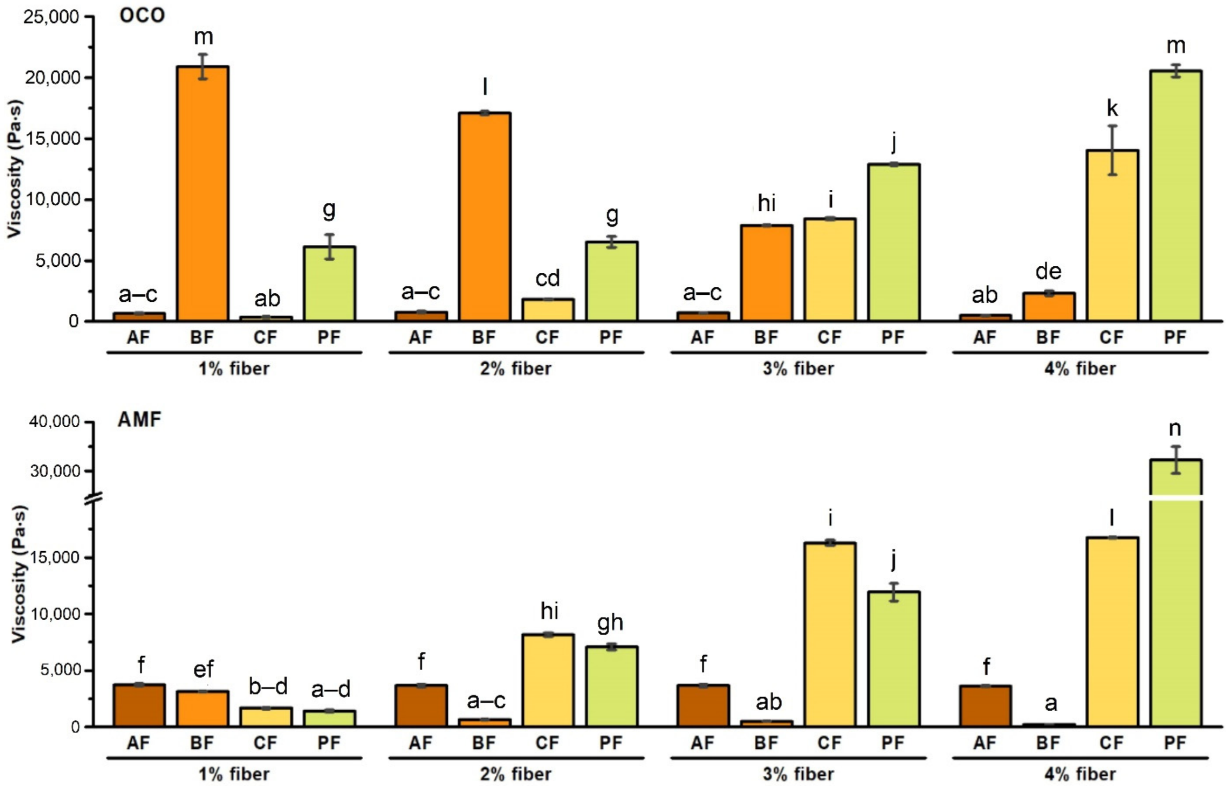

Figure 3. Effect of fiber type and concentration on viscosity of PCS (processed cheese sauces) obtained on the basis of AC (acid casein) and WPC80 (whey protein concentate) with OCO (organic coconut oil) or AMF (anhydrous milk fat) ($p < 0.05$). Letters (a–n) indicate significant differences at $p < 0.05$.

Acacia fiber contains a molecular structure that is strongly branched and has a low molecular weight may cause a change in the value of viscosity and high water solubility properties [42]. Our products had a fluid structure after adding acacia fiber and in some cases, we observed delamination in the final product. In addition, bamboo fiber is characterized by high water holding capacity. A significant reduction in viscosity with an increase in the content of fiber was observed. The composition of citrus fiber might cause a systematic increase in viscosity in final products. Carbohydrates, including pectin and cellulose, represent the majority of CF. Due to the pectin components' acidic nature, apparent viscosity and gelling properties make this fiber perfect for food applications [21]. The highest values of viscosity for the sauce with potato fiber may be a result of the properties described in Section 3.1, i.e., a higher amount of insoluble fraction and low viscosity [22]. It can bind and reduce the free water in sauce and restrict the food system's movement and, because of it, an increase in the viscosity was noted.

In addition, the differences between a product with OCO or AMF were observed. Sauces with OCO in few cases had higher viscosity value than products with AMF (Figure 3). Basically, interactions between the fat-solid component involve the coating of particles by fat. Fat penetrates the solid matrix and causes viscosity effects [35]. It may suggest that OCO blends better in our sauce base structure and individual products obtained higher viscosity values than those with AMF addition. It was also observed that the viscosity of the AMF is related to factors such as the shear rate or temperature. Viscosity at a higher shear rate (1440 s^{-1}) was lower compared to 90 s^{-1}. In addition, the temperature used during the experiment (45 °C to 17.5 °C) impacted the examined sample. The described feature increases to a certain point and then progressively decreases [43]. The pH of the product can also influence on the viscosity. Adsorption of whey proteins used to prepare the sauces on fat globule surfaces of coconut oil depends on pH value. It was observed that the volume of whey proteins adsorbed on fat at pH 5.0 in coconut emulsions was more remarkable in comparison to other tested pH (3.0, 7.0 and 9.0) [44]. During our products' preparation, we applied pH 5.8, which seemed to work well with the OCO, compared to samples with AMF.

3.3. Viscoelastic Properties

Generally, fluids and semisolids that exhibit yield stress are characterized by a structural network, the strength of which is dependent on the type of interactions between each molecule that composes it. Furthermore, the structure of the dispersed phase can have an impact on the structural network of fluids. Yield stress determines the essential features of cheese sauces. The rheological property of liquid and solid materials describing the material structure's strength is defined as the minimum stress necessary to make a tested material flow [45]. Table 1 presents the value (Pa) of yield stress (yield point) in an instance when the product cannot sustain more elastic deformation and start flowing. In most of the samples, the value of yield stress increased along with the amount of added fiber. In contrast, a decrease in the yield stress parameter and a higher amount of added fiber was observed in sauces with OCO/AMF + AF. In sauces with AMF + BF, the testing parameter values increased in product with the addition of 1–3% fiber and were much lower regarding 4% BF. In addition, the values of yield stress—both in samples with the addition of AF and BF—were much lower than other tested samples.

Whey—due to its structural elements, the occurring proteins including β-lactoglobulin, α-lactalbumin and immunoglobulins—can create three-dimensional structures held together by disulfide bridges [46]. The described components, α-lactoglobulin and β-lactalbumin, can stabilize emulsions because of their capability to adsorb oil–water interfaces [47]. When analyzing the obtained results, it can be concluded that semisolid fluids such as cheese sauce presented shear-thinning behavior. Regarding this, there are a few hypotheses: One of them explains that, due to large molecular chains that randomly tumble and with the sizeable hydrodynamic radius, it could significantly affect the resistance to fluid flow under low shear. The increasing shear rate value proves that these large molecular chains align themselves in the direction of shear force and, during that process, they become resistant to shear force decrease [48]. We also observed that the amount of stress that the product needs in order to experience a permanent deformation was the highest in sauces with AMF + 4% CF, AMF + 3 and 4% PF and OCO + 3 and 4% PF. The value they reached was higher than 1000 Pa. These results were correlated with hardness measurements. The described sauces also have the most outstanding hardness values, suggesting that they had the most compact structure. Yield stress is also an essential product characteristic that determines its texture and consumer sensory perception during its use and application [45].

In Table 2, the influence of dietary fiber's concentration on PCS with the addition of OCO or AMF on storage (G′) and loss (G″) moduli were presented. When G′ exceeds G″, it means that tested material has a structure associated with yield stress. We can observe in our product that the value of G′ was higher than G″ at infinitely low frequencies.

The measurement results for G′ and G″ were very diverse. Regarding tested sauces with PF + AMF/OCO (2–3%) and BF + AMF (1–4%), the value of storage and loss moduli increased along with the amount of added fiber. The prepared samples behave as an elastic solid, although this is not ideal because some accumulated mechanical energy is dissipated. The presented results may prove that tested sauces have strain-dependent networks. They tend to flow differently than true gels and they are more solution-like under comparatively minor stresses [49]. In samples with AF + AMF (1–4%) and BF + OCO (1–3%), a decrease in the described features along with the amount of added fibers was observed. The values of the storage (G′) modulus were higher than the loss (G″) modulus in all tested PCS. It suggests that the prepared samples exhibited elastic properties during the whole measurement. The presented results are consistent with the data obtained during the tests of cheese sauces with the same fibers based on rapeseed oil. The G′ values exhibited higher values in sauces with bamboo and potato fibers. Our research from 2020 suggests that this may be caused because PF and BF consist of fewer water-soluble fractions [13].

In addition, a relationship in decreasing and increasing of values between storage modulus and hardness was noted. Regarding PCS with AMF, sauces with 1% of AF and PF had the highest G′ and G″ values, implying that the gel structure of the PCS was the strongest and formed a more flexible system than products with a more significant addition of fibers. In other products, this tendency was reversed. The highest values of loss and storage moduli were observed in 3% AF + OCO sauce (60,086 Pa) and the lowest in 2% AF + OCO (0.70 Pa) and are consistent with our observations. This could be because acacia fiber has a higher amount of water-soluble fractions. The higher content of the insoluble fraction of the used fiber most likely served as a gel filler. This can cause the reinforcement of the structure.

Another tested feature was the tan (δ) of tested PCS. The loss tangent (tan (δ)) was described as follows:

$$\tan(\delta) = G''/G' \quad (3)$$

It is defined as a phase angle between the viscous and elastic components of material behavior [50]. When G′ represents higher values than G″, it means that tan (δ) <1. Such values indicate that measured samples have more elastic than viscous properties. Values of tan (δ) for each of the tested products are lower than one, which means that obtained PCS have elastic properties. Additionally, we noted that the products with AMF and AF, CF, or PF generally have lower tan (δ) values than other tested sauces samples. Lopez et al. [51] observed that the anhydrous milk fat melts at 40–41 °C [51]. Melted fat may partially fill the inter-protein spaces in a product based on WPC and the remaining part of it increases the volume of the cheese sauce sample, causing a boost in the value of G′ and G″ modules and simultaneously a reduction in the value of tan (δ). Additionally, the temperature used during the homogenization process (80 °C) may be connected with the process of gel formation. When lactose content in concentrates and isolates is low, their gelation temperature is shifted during whey protein's denaturation [52].

Table 2. Effect of different fibers concentration on PCS (processed cheese sauces) obtained on the basis of AC (acid casein) with OCO (organic coconut oil) or AC (acid casein) with AMF (anhydrous milk fat) on value of G′ and G″ moduli, tan (δ) and yield stress.

Fat/Oil	Fiber Type	G′ (Pa)				G″ (Pa)				tan (δ)				Yield Stress (Pa)			
		Fiber Content (%)				Fiber Content (%)				Fiber Content (%)				Fiber Content (%)			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
OCO	AF	3.25 ^{a} ±0.69	0.70 ^{a} ±0.12	60,086 ^{m} ±8319	785 ^{cd} ±79	1.17 ^{a} ±0.55	0.55 ^{a} ±0.09	43,014 ^{i} ±5590	361 $^{b–d}$ ±74	0.40 ^{j} ±0.22	0.79 ^{r} ±0.10	0.72 ^{p} ±0.08	0.47 ^{l} ±0.12	601 ^{k} ±1	206 ^{f} ±1	212 ^{f} ±1	1.04 ^{a} ±0.03
	BF	13,384 ^{j} ±35	568 $^{b–d}$ ±7	383 ^{bc} ±1	3774 ^{hi} ±10	970 ^{de} ±1	278 $^{a–c}$ ±28	134 $^{a–c}$ ±1	1235 ^{ef} ±25	0.07 ^{a} ±0.01	0.49 ^{lm} ±0.05	0.35 $^{g–i}$ ±0.01	0.33 $^{d–g}$ ±0.01	1.82 ^{a} ±0.01	40.3 ^{b} ±0.2	81.5 ^{c} ±1.6	407 ^{h} ±2
	CF	11.4 ^{a} ±0.1	2703 $^{e–h}$ ±211	546 $^{b–d}$ ±22	3122 $^{f–h}$ ±22	7.68 ^{a} ±0.14	775 $^{c–e}$ ±66	181 $^{a–c}$ ±32	950 ^{de} ±5	0.67 ^{o} ±0.01	0.29 ^{cd} ±0.05	0.33 $^{e–g}$ ±0.07	0.30 ^{de} ±0.01	47.9 ^{b} ±0.1	415 ^{hi} ±1	894 ^{m} ±12	963 ^{n} ±12
	PF	23,837 ^{l} ±841	951 ^{cd} ±13	2824 $^{e–h}$ ±38	13,784 ^{j} ±210	16,727 ^{h} ±1364	394 $^{b–d}$ ±43	874 $^{c–e}$ ±12	5413 ^{g} ±545	0.70 ^{op} ±0.07	0.41 ^{jk} ±0.05	0.31 $^{d–f}$ ±0.01	0.39 ^{ih} ±0.04	205 ^{f} ±1	415 ^{hi} ±3	1254 ^{r} ±18	2973 ^{t} ±46
AMF	AF	1158 $^{c–e}$ ±36	844 ^{cd} ±10	633 $^{b–d}$ ±4	177 ^{b} ±3	411 $^{b–e}$ ±6	322 $^{b–d}$ ±11	210 $^{a–c}$ ±2	74 ^{ab} ±7	0.35 $^{g–i}$ ±0.01	0.38 $^{h–j}$ ±0.01	0.33 $^{d–g}$ ±0.01	0.42 ^{k} ±0.04	17.3 ^{a} ±0.3	16.1 ^{a} ±0.4	6.42 ^{a} ±0.4	0.66 ^{a} ±0.36
	BF	6.12 ^{a} ±0.09	1744 $^{d–e}$ ±13	2650 $^{e–h}$ ±30	4717 ^{i} ±117	3.82 ^{a} ±0.12	906 $^{c–e}$ ±11	944 ^{de} ±8	1922 ^{f} ±217	0.62 ^{n} ±0.01	0.52 ^{m} ±0.01	0.32 $^{d–g}$ ±0.01	0.41 ^{jk} ±0.05	108 ^{d} ±3	161 ^{e} ±3	219 ^{f} ±1	6.81 ^{a} ±0.01
	CF	29.9 ^{ab} ±0.02	3451 ^{gh} ±77	336 ^{bc} ±11	2022 $^{d–f}$ ±10	7.50 ^{a} ±0.05	769 $^{c–e}$ ±15	116 $^{a–c}$ ±2	523 $^{b–e}$ ±4	0.25 ^{bc} ±0.01	0.22 ^{b} ±0.01	0.34 $^{e–h}$ ±0.01	0.26 ^{bc} ±0.01	6.81 ^{a} ±0.01	338 ^{g} ±2	562 ^{j} ±5	1217 ^{p} ±13
	PF	3773 ^{hi} ±10	1269 $^{c–e}$ ±57	2511 $^{e–g}$ ±16	19,815 ^{k} ±3069	1177 ^{e} ±38	573 $^{b–e}$ ±15	770 $^{c–e}$ ±4	5242 ^{g} ±1756	0.31 $^{d–f}$ ±0.01	0.45 ^{kl} ±0.02	0.31 $^{d–f}$ ±0.01	0.26 ^{bc} ±0.05	429 ^{i} ±2	706 ^{l} ±5	1143 ^{o} ±4	1835 ^{s} ±1

Data are presented as means ± SD (standard deviation). $^{a–t}$ Means within columns and rows for each parameter (G′, G″, tan (δ) or yield stress) with different superscripts are significantly different ($p < 0.05$, Duncan's test).

3.4. Principal Component Analysis (PCA)

A PCA was applied to compare the samples of examined processed cheese sauces and analyze the variability in their physical properties parameters. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was 0.637 and the Bartlett test of sphericity (Chiˆ2 value 183.147) reached statistical significance (p-value < 0.001), providing the basis for the application of PCA analysis. The results showed that a high concentration of CF and PF fiber type was the factor that most affected most of the physical parameters, irrespective of the oil/fat type. The map obtained after PCA was applied is shown in Figure 4. The first two principal components explained a high amount of the variance (77.09%), from which the first component explained most of the data variability (46.08%). It was negatively associated with hardness, viscosity, adhesiveness and yield stress (Figure 4, inset), although the correlation matrix indicated that the information provided by these four parameters was very similar. This element was primarily responsible for the separation of the examined processed cheese sauces with the high concentrations (3 or 4%) of CF and PF fiber type (Figure 4); in particular, both OCO and AMF samples with 4% of PF fiber were clearly separated from the rest and located on the negative part of the first dimension. The latter two cheese sauce samples were characterized with the highest values of yield stress, viscosity, hardness and adhesiveness (Figures 1–3, Table 1). The second component described a lower amount of the variance (31.01%) and was highly negatively correlated with G' and G'' (Figure 4, inset). The majority of samples were distributed on the positive side and only three OCO samples (1% and 4% PF and 3% AF) and 4% PF + AMF sample fell in the negative part of this component. Mostly, a 3% AF + OCO sample was significantly separated from the rest. Indeed, this sample was characterized by an extremely high value of G' (Table 1).

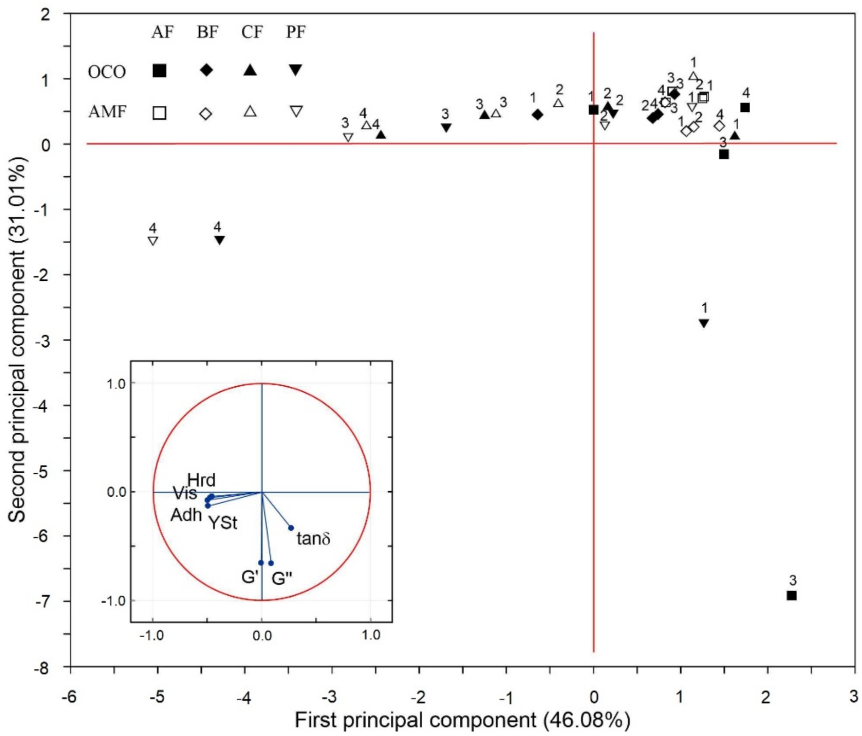

Figure 4. Principal component analysis (PCA) bi-plot for physical properties parameters (Hrd: hardness, Adh: adhesiveness, Vis: viscosity, YSt: yield stress, G': storage modulus, G'': loss modulus, tan (δ): loss tangent) of acid casein PCS with different type of fat/oil (AFM or OCO), type of fiber (AF, BF, CF, PF) and fiber concentration (1%, 2%, 3%, 4%). Inset: correlation circle between variables all of the original variables included in a PCA in the first and second principal component factorial plane (correlation biplot).

3.5. Colorimetric Measurements

Table 3 presents the color analysis results obtained using the computer vision system (CVS). One of the most prominent variables affecting consumer preference is color. Therefore, it is critical to prepare a product that is closest in appearance to consumers' preferences. As opposed to other approaches, CVS color measures are much closer to the true color of the samples. Furthermore, the obtained color shades are more saturated than those obtained using conventional colorimetric techniques [25].

The intensity of PCS color was significantly different between tested samples ($p < 0.05$) and it could be described as creamy white to creamy yellow because b* in the products with OCO addition and AF, BF, CF have lower values than a product with the addition of the same fiber but-based on AMF.

Only in the sauce with PF(1–3%) + OCO, values of b* were higher than PF + AMF. Of all tested samples, sauces with the addition of AMF were identified by the highest b* values and were the most yellow-tinted in comparison to the other samples. All tested samples had positive values of a* parameter, which indicated a slight red hue. The brightness (L*) of each of the measured samples ranged from 79 to about 88. Statistically significant differences for the L* were observed between samples in each product group ($p < 0.05$). In terms of L* value in cheese sauces obtained based on different oil/fat, it can be observed that they do not affect this parameter. Still, among different fibers, significant differences were noted ($p < 0.05$). The lowest L* was observed in a group of sauces with the addition of PF. Wadhwani [53] noticed that cheese color's prime determination has light scattered by milk fat globules [53]. We did not observe the same results in every PCS sample due to used fibers, but products with AMF addition had more yellow tones than most OCO products. Olsson, Håkansson, Purhagen and Wendin [54] tested influence of emulsion intensity on the textural characteristics of full-fat mayonnaise. They suggested another factor that can cause changes in the color of the final product. They noticed that reducing droplet size during the homogenization process leads to a whiter of the final product [54]. We also noticed that used fibers did not affect the color of our product. The bamboo fiber used to prepare samples had a white color, whereas acacia and citrus fiber had a creamy white shade. Only potato fiber was characterized by visible light-brown particles, the color of which was not so diametrically visible in the sauce's final color.

For a comprehensive description of the product's color, we provide information about another attribute: chroma and hue angle. All the tested products had different hue angles. The lowest value characterized samples with OCO + 1–3% PF ($p < 0.05$). The measurements showed that sauces' colors were between 5–20, which corresponds to the orange color. The other appearance parameter describing the developed product is chroma. For a sauce obtained with OCO's addition, chroma's highest content was observed among samples with 1–3% PF, with no significant difference between them ($p > 0.05$). Meanwhile, these cheese sauces were characterized by the highest b* and a* representing more green and yellow final product tones. PCS obtained-based on AC + AMF had the highest content of chroma in products with the addition of AF, BF and CF ($p < 0.05$).

Table 3. Effect of different fibers concentration color (CIE Lab standards) of acid casein PCS (processed cheese sauces) with WPC80 (whey protein concentrate) and OCO (organic coconut oil) or AMF (anhydrous milk fat).

Fat/Oil	Fiber Type	L*				a*				b*				Chroma				Hue			
		Fiber Content (%)				Fiber Content (%)				Fiber Content (%)				Fiber Content (%)				Fiber Content (%)			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
OCO	AF	85.0^{gh} ±1.5	$85.9^{h–k}$ ±0.9	$86.9^{k–n}$ ±0.4	85.0^{gh} ±0.6	6.14^{n} ±0.69	5.71^{m} ±0.49	$4.29^{f–i}$ ±0.49	5.57^{lm} ±0.53	19.4^{hi} ±2.2	$19.9^{h–j}$ ±1.6	7.86^{a} ±1.21	14.7^{cd} ±1.5	20.4^{ij} ±2.3	20.7^{ij} ±1.6	8.96^{ab} ±1.23	$15.7^{d–f}$ ±1.5	$17.6^{k–n}$ ±1.6	$16.1^{i–m}$ ±1.1	28.8^{r} ±3.0	20.8^{op} ±2.1
	BF	88.9^{p} ±0.4	88.6^{op} ±0.5	$87.1^{l–n}$ ±1.5	$87.1^{l–n}$ ±0.9	$2.43^{a–d}$ ±0.53	$2.43^{a–d}$ ±0.53	$2.14^{a–c}$ ±0.69	$3.71^{e–g}$ ±0.49	9.57^{b} ±0.53	9.29^{b} ±0.76	7.14^{a} ±2.11	9.29^{b} ±0.95	9.88^{b} ±0.56	9.61^{b} ±0.81	7.47^{a} ±2.19	10.0^{b} ±0.9	$14.2^{g–j}$ ±3.0	$14.6^{h–k}$ ±2.7	$16.8^{j–n}$ ±3.3	21.9^{p} ±3.1
	CF	$88.1^{n–p}$ ±0.7	$87.6^{m–p}$ ±0.5	$86.6^{j–m}$ ±0.5	$86.4^{i–l}$ ±0.8	1.71^{a} ±0.76	$2.00^{a–c}$ ±0.82	1.85^{ab} ±0.69	2.71^{cd} ±0.76	8.57^{ab} ±0.53	9.00^{ab} ±0.58	8.14^{ab} ±1.99	9.71^{b} ±0.76	8.77^{ab} ±0.57	9.25^{ab} 0.59	8.39^{ab} ±1.99	10.1^{b} ±0.7	$11.3^{e–g}$ ±4.7	$12.5^{f–h}$ ±5.0	$13.5^{g–i}$ ±5.8	$15.7^{i–l}$ ±4.8
	PF	81.1^{bc} ±1.5	80.0^{ab} ±0.1	79.6^{a} ±2.5	83.0^{de} ±1.2	3.00^{de} ±0.58	2.71^{cd} ±0.76	$5.43^{k–m}$ ±1.27	$4.57^{h–j}$ ±0.53	26.3^{l} ±1.5	26.9^{l} ±1.9	24.1^{k} ±2.9	8.00^{ab} ±0.82	26.5^{kl} ±1.5	27.0^{l} ±1.9	24.7^{k} ±3.0	9.22^{ab} ±0.93	6.50^{ab} ±1.19	5.71^{a} ±1.23	$12.5^{f–h}$ ±1.6	29.7^{r} ±1.9
AMF	AF	$85.6^{g–j}$ ±1.0	85.0^{gh} ±1.6	82.6^{de} ±1.5	82.0^{cd} ±0.6	3.57^{ef} ±0.79	$3.71^{e–g}$ ±0.76	$4.43^{g–i}$ ±0.79	7.86^{o} ±0.38	20.3^{ij} ±2.5	21.6^{j} ±1.9	26.9^{l} ±1.6	23.7^{k} ±1.6	20.6^{ij} ±2.6	21.9^{j} ±1.9	27.2^{l} ±1.6	25.0^{k} ±1.6	$9.90^{c–f}$ ±1.50	$9.77^{c–f}$ ±1.84	$9.37^{b–e}$ ±1.68	$18.4^{l–o}$ ±0.8
	BF	$88.1^{n–p}$ ±1.6	$86.9^{k–n}$ ±0.9	$87.3^{m–o}$ ±0.8	$87.9^{m–p}$ ±1.2	$2.57^{b–d}$ ±0.53	$4.14^{f–h}$ ±0.38	$2.00^{a–c}$ ±0.01	$2.14^{a–c}$ ±0.38	21.3^{j} ±4.1	14.7^{cd} ±1.7	$16.6^{d–g}$ ±1.0	16.9^{fg} ±1.7	21.4^{j} ±4.1	$15.3^{c–e}$ ±1.7	$16.7^{e–g}$ ±1.0	$17.0^{e–g}$ ±1.7	$7.00^{a–c}$ ±1.67	$15.8^{i–l}$ ±1.4	$6.90^{a–c}$ ±0.41	$7.32^{a–d}$ ±1.59
	CF	$85.3^{g–i}$ 0.5	83.4^{ef} 1.0	80.3^{ab} 0.5	79.7^{a} 0.8	$4.71^{h–k}$ ±0.49	$5.29^{j–l}$ ±0.76	5.71^{jk} ±0.49	5.57^{lm} ±0.79	$14.9^{c–e}$ ±1.1	$16.0^{d–f}$ ±1.1	17.7^{fg} ±1.1	18.1^{gh} ±0.7	$15.6^{c–e}$ ±1.1	$16.9^{e–g}$ ±1.5	$17.7^{f–h}$ ±1.1	19.0^{hi} ±0.6	$17.6^{k–n}$ ±1.5	$18.2^{l–o}$ ±1.6	$18.9^{m–o}$ ±1.5	$17.1^{j–n}$ ±2.6
	PF	$88.0^{m–p}$ ±1.4	84.3^{fg} ±1.1	81.9^{cd} ±1.3	80.0^{ab} ±0.8	3.14^{de} ±0.38	$4.43^{g–i}$ ±0.53	$5.00^{i–l}$ ±0.82	5.57^{lm} ±0.53	17.6^{fg} ±1.0	13.0^{c} ±1.3	13.1^{c} ±1.6	$15.7^{d–f}$ ±1.0	17.9^{gh} ±1.0	13.7^{c} ±1.3	14.1^{cd} ±1.7	$16.7^{e–g}$ ±1.0	$10.1^{d–f}$ ±0.9	$18.9^{l–o}$ ±1.9	20.8^{op} ±1.5	$19.5^{n–p}$ ±1.2

Data are presented as means ± SD (standard deviation). $^{a–r}$ Means within columns and rows for each parameter (L*, a*, b*, Chroma or Hue) with different superscripts are significantly different ($p < 0.05$, Duncan's test)

The color of individual products was influenced by both the addition of various oils and dietary fibers (Figure 5). PCS obtained based on AC + AMF have more yellow tones than sauces with AC + OCO. This could be related to the color of milk fat. It has natural yellow tones connected with carotenoids, vitamin A and other pigments [55].

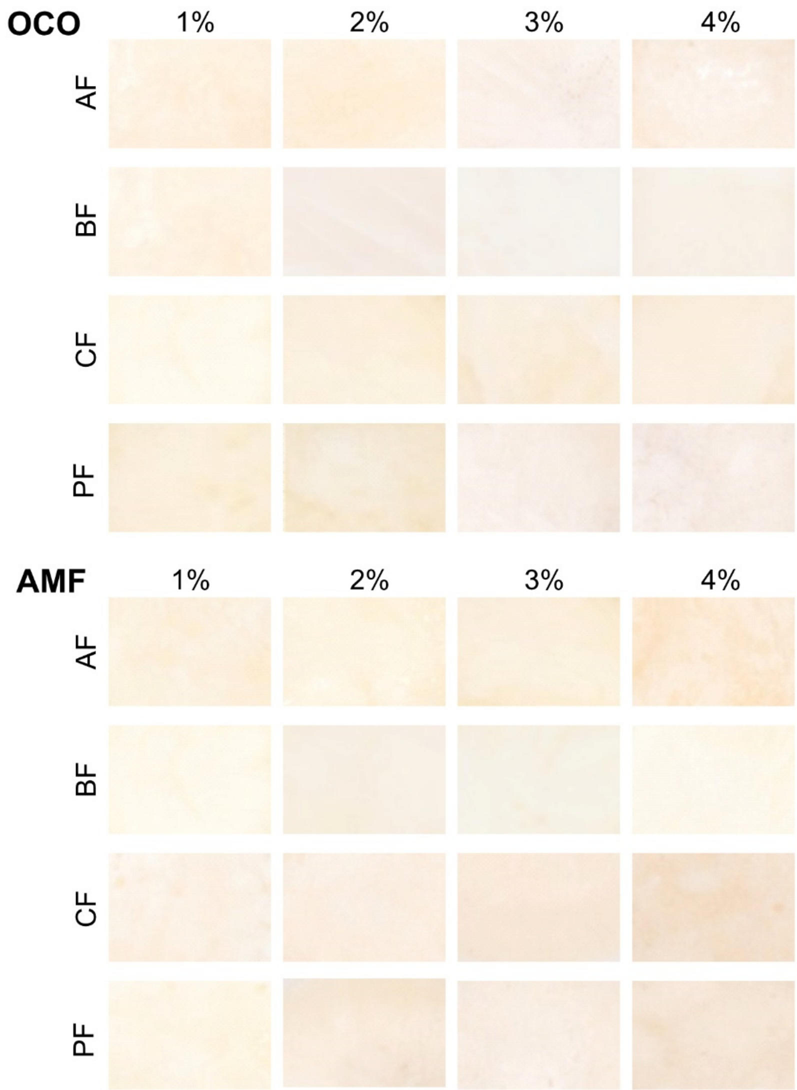

Figure 5. Effect of different fibers concentration of color of acid casein PCS (processed cheese sauces) with WPC80 (whey protein concentrate) and OCO (organic coconut oil) or AMF (anhydrous milk fat) measured with CVS (computer vision system).

Color distinctions represented by ΔE values between 00.00 and 1.5, according to Inami et al. [26], are incredibly slight; consumers can notice slight changes between 1.5–6.0 [26]. Values of ΔE above 6 prove the significant influence of the dietary fiber and fat source on PCS's color difference between prepared samples. Table 4 presents the results of color intensity measurements of PCS expressed by NBS units (ΔE × 0.92). A comparison of tested samples between each other showed that most of them characterized by NBS higher than 1.5. This means that changes can be noticeable. The most visible changes occur in CF + OCO compared to AF + AMF and AF + OCO compared to AF + AMF. These results follow the results discussed above. Dietary fibers from various sources have similar colors. In smaller amounts, their addition to sauce does not change the final products' shade significantly as fat used in production. The only amount of added fibers is the factor that influenced the color of the products. More fiber increased the overall color of the PCS.

Table 4. Effect of different fibers, AC (acid casein), WPC80 (whey protein concentrate) and OCO (organic coconut oil) or AMF (anhydrous milk fat) on color differences of PCS (processed cheese sauces) expressed by NBS units (ΔE × 0.92) measured with CVS (computer vision system).

			OCO																AMF															
			AF(%)				BF(%)				CF(%)				PF(%)				AF(%)				BF(%)				CF(%)				PF(%)			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
OCO	AF(%)	1	-																															
		2	1.03	-																														
		3	10.9	11.2	-																													
		4	4.3	4.9	6.6	-																												
	BF(%)	1	10.3	10.3	3.0	6.6	-																											
		2	10.4	10.5	2.7	6.6	0.4	-																										
		3	12.0	12.2	2.09	7.9	2.8	2.4	-																									
		4	9.8	10.0	1.4	5.6	2.05	1.8	2.4	-																								
	CF(%)	1	10.8	11.2	2.7	7.2	1.4	1.04	1.7	2.16	-																							
		2	10.6	10.7	2.4	6.6	2.4	1.04	1.8	1.7	0.7	-																						
		3	11.2	11.4	2.3	7.09	2.6	2.2	1.06	2.06	1.4	1.2	-																					
		4	9.5	9.8	2.3	5.4	2.4	2.08	2.5	1.19	2.1	1.4	1.7	-																				
	PF(%)	1	7.8	7.8	17.8	11.5	17.0	17.1	18.5	16.6	17.6	17.0	17.5	16.0	-																			
		2	8.9	8.9	18.7	12.4	17.9	18.0	19.3	17.5	18.5	17.9	18.3	16.9	1.2	-																		
		3	6.6	7.0	16.4	10.0	16.1	16.2	17.3	15.4	16.6	16.0	16.4	14.9	3.3	3.6	-																	
		4	10.7	11.3	3.6	6.5	5.9	5.6	4.5	4.03	5.4	4.9	4.2	3.9	17.0	17.7	15.2	-																
AMF	AF(%)	1	2.6	2.02	11.5	5.5	10.4	10.6	12.3	10.2	11.2	10.7	11.3	9.8	6.9	8.0	6.8	11.6	-															
		2	3.02	2.6	12.8	6.6	11.7	11.9	13.5	11.5	12.5	11.9	12.6	11.1	5.7	6.8	5.7	12.7	1.3	-														
		3	7.4	7.2	17.9	11.5	17.1	17.2	18.8	16.7	17.8	17.2	17.8	16.3	2.0	2.9	3.9	17.4	6.7	5.4	-													
		4	5.08	5.4	15.6	9.0	15.3	15.4	16.8	15.6	16.0	15.4	15.9	14.3	5.1	5.9	3.2	14.8	6.0	5.1	4.4	-												
	BF(%)	1	4.7	3.8	12.5	7.3	10.8	11.1	13.1	11.1	11.7	11.3	12.2	10.8	7.9	9.06	8.6	13.2	2.6	3.1	7.4	7.8	-											
		2	5.01	5.08	6.3	2.2	5.3	5.4	7.2	5.0	6.2	5.6	6.4	4.8	12.0	13.0	11.0	7.1	5.3	6.6	11.3	10.0	6.3	-										
		3	5.06	4.7	8.3	4.3	6.6	6.8	8.7	6.9	7.4	7.0	7.8	6.4	10.6	11.6	10.4	9.2	4.0	5.3	10.7	9.8	4.4	2.7	-									
		4	5.09	4.7	8.6	4.6	6.8	7.04	9.0	7.2	7.7	7.3	8.2	6.8	10.7	11.7	10.6	9.6	4.0	5.3	10.6	9.8	4.1	2.9	0.6	-								
	CF(%)	1	4.4	4.7	6.7	0.9	6.3	6.3	7.7	5.5	6.9	6.3	6.9	5.2	11.3	12.2	10.0	6.7	5.1	6.2	11.3	9.1	6.7	1.6	3.5	3.8	-							
		2	3.0	3.8	8.8	2.4	8.7	8.7	9.9	7.8	9.2	8.6	9.0	7.4	9.3	10.2	7.7	8.0	4.2	5.0	9.4	7.0	6.5	3.9	4.7	5.1	2.5	-						
		3	4.6	5.5	11.0	5.1	11.3	11.3	12.0	10.1	11.6	11.0	11.1	9.7	8.3	8.9	5.9	9.3	5.8	6.1	8.8	6.1	8.4	6.8	7.4	7.8	5.4	3.0	-					
		4	5.05	5.9	11.6	5.8	11.9	11.9	12.6	10.7	12.2	11.6	11.7	10.2	8.01	8.5	5.5	9.8	6.1	6.1	8.6	6.0	8.7	7.4	7.8	8.3	6.0	3.6	0.7	-				
	PF(%)	1	4.2	3.7	9.08	4.4	7.5	7.7	9.7	7.7	8.4	8.0	8.9	7.4	10.2	11.3	10.0	10.0	3.4	4.6	10.0	9.0	3.4	3.0	1.5	1.1	3.8	4.7	7.5	8.0	-			
		2	6.1	6.6	5.3	2.0	5.6	5.5	6.3	4.3	5.9	5.3	5.5	3.9	12.7	13.5	11.1	4.8	6.9	8.0	13.7	10.6	8.6	2.9	4.9	5.3	2.0	3.6	5.8	6.4	5.6	-		
		3	6.5	7.3	6.7	3.3	7.6	7.5	7.7	6.05	7.7	7.0	6.9	5.6	12.4	13.0	10.3	4.8	7.6	8.4	12.7	10.1	9.7	4.9	6.5	7.0	3.5	3.6	4.5	5.1	7.2	2.3	-	
		4	5.7	6.7	9.7	4.7	10.4	10.3	10.7	9.0	10.5	9.9	9.8	8.5	10.2	10.6	7.7	7.7	6.9	7.3	10.6	7.9	9.5	6.5	7.5	8.0	5.0	3.3	1.9	2.2	7.9	4.8	3	-

3.6. Density and Water Activity

Results of density and water activity of PCS have been presented in Table 5. Generally, fibers and fat/oil affected the density of processed cheese sauces. Fat/oil can form emulsions, which are dispersions of a fat or oil into water (or water into oil/fat). The emulsification process of fat into food products gives them unique texture qualities [56].

Table 5. Effect of different fibers concentration on density and water activity of acid casein PCS (processed cheese sauces) with WPC80 (whey protein concentrate) and OCO (organic coconut oil) or AMF (anhydrous milk fat).

Fat/Oil	Fiber Type	Density (g/mL)				Water Activity			
		Fiber Content (%)				Fiber Content (%)			
		1	2	3	4	1	2	3	4
OCO	AF	1.071 $^{g–i}$ ±0.001	1.067 $^{f–h}$ ±0.002	1.065 $^{e–g}$ ±0.004	1.061 $^{c–e}$ ±0.001	0.998 ^{c} ±0.001	0.989 ^{bc} ±0.002	0.992 ^{bc} ±0.003	0.979 ^{b} ±0.001
	BF	1.046 ^{a} ±0.001	1.047 ^{a} ±0.004	1.058 ^{bc} ±0.002	1.054 ^{b} ±0.003	0.990 ^{bc} ±0.001	0.980 ^{bc} ±0.001	0.981 ^{bc} ±0.002	0.981 ^{bc} ±0.001
	CF	1.064 $^{d–f}$ ±0.002	1.068 $^{f–h}$ ±0.002	1.068 $^{f–h}$ ±0.00	1.070 $^{g–i}$ ±1.002	0.985 ^{bc} ±0.004	0.988 ^{bc} ±0.003	0.988 ^{bc} ±0.001	0.990 ^{bc} ±0.001
	PF	1.072 ^{hi} ±0.002	1.071 $^{g–i}$ ±0.001	1.081 $^{j–l}$ ±0.007	1.091 ^{n} ±0.007	0.984 ^{bc} ±0.001	0.985 ^{bc} 0.001	0.980 ^{bc} ±0.001	0.990 ^{bc} ±0.001
AMF	AF	1.045 ^{a} ±0.004	1.06 ^{cd} ±0.003	1.044 ^{a} ±0.002	1.078 ^{jk} ±0.004	0.988 ^{bc} ±0.001	0.985 ^{bc} 0.003	0.986 ^{bc} ±0.001	0.984 ^{bc} ±0.001
	BF	1.068 $^{f–h}$ ±0.001	1.068 $^{f–h}$ ±0.001	1.076 ^{ij} ±0.005	1.086 $^{l–n}$ ±0.005	0.988 ^{bc} ±0.001	0.984 ^{bc} 0.001	0.985 ^{bc} ±0.001	0.971 ^{a} ±0.005
	CF	1.045 ^{a} ±0.005	1.084 $^{k–m}$ ±0.005	1.080 ^{jk} ±0.003	1.090 ^{n} ±0.006	0.996 ^{bc} ±0.004	0.990 ^{bc} 0.003	0.990 ^{bc} ±0.001	0.980 ^{bc} ±0.001
	PF	1.056 ^{bc} ±0.002	1.079 ^{jk} ±0.001	1.088 ^{mn} ±0.001	1.098 ^{o} ±0.001	0.980 ^{bc} ±0.001	0.990 ^{bc} 0.001	0.990 ^{bc} ±0.001	0.990 ^{bc} ±0.003

Data are presented as means ± SD (standard deviation). $^{a–o}$ Means within columns and rows for each parameter (Density or Water activity) with different superscripts are significantly different ($p < 0.05$, Duncan's test).

Density decreases when fats are changing their form from solid to liquid. During the melting process, the volume of fats increases and, therefore, the density decreases. The density of milk fat at 15 °C is between 0.935–0.943 and for coconut oil, 0.919–0.937 [57]. This may indicate that oil/fat used in research impacted products and dietary fiber used. This seems to be confirmed by the values between the individual concentrations. The density of PCS with AMF increased along with added fiber in product with BF, CF, PF ($p < 0.05$) and in sauces with OCO + CF and PF. However, the opposite relationship in the product with OCO + AF was noted. These results overlap with the results of hardness and the obtained products. For sauces with the addition of OCO, it can be seen that the increase in hardness is correlated with the density values. In products with AMF, the results were not so precise. We do not fully understand what causes these fluctuations in the density of the obtained products. Because they occurred mainly with sauces with the addition of AMF, we considered that animal fat used in production with the addition of specific fibers causes these changes, which may indicate the instability of the product structure.

Water activity (a_w) and pH significantly impact fresh food, which offers a favorable environment for molds and yeast to grow [58]. The water activity of PCS with OCO lowered only for sauces with AF and BF; however, the decrease was not significant ($p > 0.05$). The lowest water activity was observed in the sample with 4% AF and AMF (0.979). In PCS with OCO, the change in fiber concentration influenced water activity only in the product with 4% BF (0.971) ($p > 0.05$). The a_w results between obtained processed cheese sauce are similar to each other. Coconut oil-in-water emulsion is described as an unstable solution [59], so it may be connected to dietary fibers added to products.

In turn, AMF is manufactured by removing the water phase from butter [60]. Among all tested sauces, PCS with bamboo fiber was characterized with the lowest value of a_w, which is connected to its significant water holding capacity and fat binding capacities [61].

The FDA (Food and Drug Administration) recommends that food products with a pH above 4.6 is stable if its water activity is 0.85 or less. The PCS were obtained in pH 5.8, suggesting that observed a_w is the right condition for undesired microflora development. Therefore, it is critical to keep the obtained cheese sauces at the refrigeration temperature.

4. Conclusions

Rheological and textural properties of PCS were influenced by fat/oil and different amounts of dietary fibers. An increasing tendency of features including hardness, adhesiveness and viscosity in sauces with CF and PF addition prepared based on OCO or AMF was observed. OCO blends better in prepared, processed sauce and individual samples received higher viscosity values than those with anhydrous milk fat.

PCS presented shear-thinning behavior connected with yield stress and tan (δ) values, which indicated that all prepared samples had elastic properties.

The computer vision system (CVS) analysis showed that the prepared product's color was associated with added fibers and different fat sources. The samples resulted in more intense colors, which may be visible to consumers (NBS). An increase in the density of sauces with CF and PF with AMF or OCO was correlated with their hardness. The water activity of processed cheese sauces obtained with OCO or AMF was not influenced by fiber type and concentration.

The observed textural, rheological and color features of the prepared sauces suggested that tested fibers can be used as an addition to processed cheese sauces based on acid casein and different oil/fat source. From a consumer point of view, sauces with the addition of AMF looked more like a commercial product, but both sources (OCO/AMF) seemed to be a good base according to physically and chemically stabilizing processed cheese sauces.

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Conflicts of Interest: The authors declare no conflict of interest in this paper.

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9. Oświadczenie współautorów publikacji stanowiących przedmiot rozprawy doktorskiej

Lublin, 04.04.2021

Oświadczenie autorów publikacji

Niniejszym oświadcza się, że publikacja:

Szafrańska J. O., Sołowiej B. G. (2019). Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects. *Journal of Food Process Engineering*, 43(4), 3, 1-14.

powstała w wyniku poniżej określonego, indywidualnego wkładu pracy współautorów:

Szafrańska Jagoda O. - współtworzenie koncepcji pracy, dokonanie przeglądu literatury, interpretacja danych literaturowych, napisanie manuskryptu oraz przygotowanie odpowiedzi na recenzje.

Sołowiej Bartosz G. - współtworzenie koncepcji pracy, pomoc w przygotowaniu manuskryptu i odpowiedzi na recenzje, pełnienie roli autora korespondencyjnego.

mgr inż. Jagoda O. Szafrańska

dr hab. Bartosz G. Sołowiej, prof. UP

Lublin, 04.04.2021

Oświadczenie autorów publikacji

Niniejszym oświadcza się, że publikacja:

Szafrańska J. O., Muszyński S., Sołowiej B. G. (2020). *Effect of whey protein concentrate on physicochemical properties of acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat*, LWT - Food Science and Technology, 127, 18, 1-7**.**

powstała w wyniku poniżej określonego, indywidualnego wkładu pracy współautorów:

Szafrańska Jagoda O. - współtworzenie koncepcji pracy, przygotowanie próbek do badań, wykonanie pomiarów dotyczących tekstury produktu, lepkości oraz modułów sprężystości i stratności. Przeprowadzenie analizy statystycznej i interpretacja wyników. Przygotowanie manuskryptu oraz odpowiedzi na recenzje.

Muszyński Siemowit - pomoc w przeprowadzeniu badań dotyczących analizy barwy, aktywności wody oraz gęstości.

Sołowiej Bartosz G. - współtworzenie koncepcji pracy, analiza wyników, pomoc w przygotowaniu manuskryptu i odpowiedzi na recenzje, pełnienie roli autora korespondencyjnego.

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Niniejszym oświadcza się, że publikacja:

Szafrańska J. O., Sołowiej B. G., (2020). Effect of different fibres on texture, rheological and sensory properties of acid casein processed cheese sauces, *International Journal of Food Science and Technology,* 55(5), 12, 1971–1979.

powstała w wyniku poniżej określonego, indywidualnego wkładu pracy współautorów:

Szafrańska Jagoda O. - współtworzenie koncepcji pracy, przygotowanie próbek do badań, wykonanie pomiarów dotyczących tekstury produktu, lepkości, modułów sprężystości i stratności oraz przeprowadzenie badania oceny organoleptycznej uzyskanych produktów. Dokonanie analizy statystycznej i interpretacja wyników. Przygotowanie manuskryptu oraz odpowiedzi na recenzje.

Sołowiej Bartosz G. - współtworzenie koncepcji pracy, analiza wyników, pomoc w przygotowaniu manuskryptu i odpowiedzi na recenzje, pełnienie roli autora korespondencyjnego.

mgr inż. Jagoda O. Szafrańska

dr hab. Bartosz G. Sołowiej, prof. UP

Lublin, 04.04.2021

Oświadczenie autorów publikacji

Niniejszym oświadcza się, że publikacja:

Szafrańska J. O., Muszyński S., Tomasevic I., Sołowiej B. G., 2021, The influence of dietary fibers on physicochemical properties of acid casein processed cheese sauces obtained with whey proteins and coconut oil or anhydrous milk fat. *Foods*, 10, 759.

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Szafrańska Jagoda O. - współtworzenie koncepcji pracy, przygotowanie próbek do badań, wykonanie pomiarów dotyczących tekstury produktu, lepkości oraz modułów sprężystości i stratności, tg kąta fazowego, granicy płynięcia. Dokonanie interpretacji wyników i przygotowanie manuskryptu oraz odpowiedzi na recenzje.

Muszyński Siemowit – pomoc w przeprowadzeniu badań dotyczących analizy barwy, aktywności wody oraz gęstości. Przeprowadzenie analizy statystycznej uzyskanych wyników.

Tomasevic Igor – pomoc przy dokonaniu analizy barwy przy pomocy Komputerowego Systemu Wizyjnego (ang. CVS – Computer Vision System) w ramach programu PROM dotyczącego międzynarodowej wymiany stypendialnej doktorantów i kadry akademickiej na Uniwersytecie
w Belgradzie (Serbia).

Sołowiej Bartosz G. - współtworzenie koncepcji pracy, analiza wyników, pomoc w przygotowaniu manuskryptu i odpowiedzi na recenzje, pełnienie roli autora korespondencyjnego.

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dr Tomasevic Igor, Assoc. Prof.

dr hab. Bartosz G. Sołowiej, prof. UP

10. Zestawienie dorobku naukowego

RB-XV-17/2021 06.05.2021 r.

Biblioteka Główna UP w Lublinie

Bibliografia Publikacji Pracowników Uniwersytetu Przyrodniczego w Lublinie

Raport autora: Jagoda Szafrańska

1. Publikacje w czasopismach naukowych

1.1. Publikacje w czasopiśmie naukowym posiadającym Impact Factor IF

Lp	Opis bibliograficzny	IF	Pkt. MNiSW
1.	**The influence of dietary fibers on physicochemical properties of acid casein processed cheese sauces obtained with whey proteins and coconut Oil or anhydrous milk fat.** [AUT.] JAGODA SZAFRAŃSKA, SIEMOWIT MUSZYŃSKI, IGOR TOMASEVIC, BARTOSZ SOŁOWIEJ. *Foods* 2021 Vol. 10 Issue 4 Article number 759, il. bibliogr. sum. DOI: 10.3390/foods10040759	4,092	70,00
2.	**Cheese sauces: Characteristics of ingredients, manufacturing methods, microbiological and sensory aspects.** [AUT.] JAGODA SZAFRAŃSKA, [AUT. KORESP.] BARTOSZ SOŁOWIEJ. *J. Food Process Eng.* 2020 Vol. 43 Iss. 4 e13364, il. bibliogr. sum. DOI: 10.1111/jfpe.13364	1,703	100,00
3.	**Effect of different fibres on texture, rheological and sensory properties of acid casein processed cheese sauces.** [AUT.] JAGODA SZAFRAŃSKA, [AUT. KORESP.] BARTOSZ SOŁOWIEJ. *Int. J. Food Sci. Technol.* 2020 Vol. 55 Iss. 5 s. 1971-1979, il. bibliogr. sum. DOI: 10.1111/ijfs.14485	2,773	70,00
4.	**Effect of emulsifying salts replacement with polymerised whey protein isolate on textural, rheological and melting properties of acid casein model processed cheeses.** [AUT. KORESP.] BARTOSZ G. SOŁOWIEJ, [AUT.] MACIEJ NASTAJ, JAGODA O.SZAFRAŃSKA, SIEMOWIT MUSZYŃSKI, WALDEMAR GUSTAW, MARTA TOMCZYŃSKA-MLEKO, STANISŁAW MLEKO. *Int. Dairy J.* 2020 Vol. 105 Article 104694 s. 1-8, il. bibliogr. sum. DOI: 10.1016/j.idairyj.2020.104694	2,512	100,00
5.	**Effect of whey protein concentrate on physicochemical properties of acid casein processed cheese sauces obtained with coconut oil or anhydrous milk fat.** [AUT.] JAGODA SZAFRAŃSKA, SIEMOWIT MUSZYŃSKI, [AUT. KORESP.] BARTOSZ SOŁOWIEJ. *Lebensm. - Wiss. Technol.* 2020 Vol. 127 Article 109434, il. bibliogr. sum. DOI: 10.1016/j.lwt.2020.109434	4.006	100,00
6.	**Effect of whey protein concentrate on physicochemical, sensory and antioxidative properties of high-protein fat-free dairy desserts.** [AUT.] KATARZYNA KUSIO, JAGODA SZAFRAŃSKA,	2,474	70,00

	WOJCIECH RADZKI, [AUT. KORESP.] BARTOSZ SOŁOWIEJ. *Appl. Sci.-Basel* 2020 Vol. 10 Iss. 20 Article 7064, il. bibliogr. sum. DOI: 10.3390/app10207064		
	Suma:	17,560	510,00

1.2 Publikacja w czasopiśmie naukowym nieposiadającym IF

L.p.	Opis bibliograficzny	IF	Pkt. MNiSW
1.	Plantarycyny - biosynteza, mechanizm działania i potencjał w zapewnianiu bezpieczeństwa żywności. [AUT.] JAGODA SZAFRAŃSKA, [AUT. KORESP.] MAGDALENA POLAK-BERECKA. *Żywn. Nauka Technol. Jakość (2016-)* 2020 Vol. 27 nr 2 (123) s. 39-49, il. bibliogr. streszcz. sum. DOI: 10.15193/zntj/2020/123/333	0,000	20.00
1.	**Ocena właściwości fizykochemicznych sosów serowych otrzymanych na bazie kazeiny kwasowej i oleju rzepakowego z dodatkiem koncentratu białek serwatkowych.** [AUT.] JAGODA SZAFRAŃSKA, [AUT. KORESP.] BARTOSZ SOŁOWIEJ, [AUT.] SIEMOWIT MUSZYŃSKI. *Przem. Spoż.* 2019 T. 73 nr 6 s. 36-42, il. bibliogr. streszcz. sum. DOI: 10.15199/65.2019.6.6	0,000	5,00
2.	**Bakteriocyny – naturalne konserwanty żywności(Bacteriocins - natural food preservatives).** [AUT. KORESP.] JAGODA SZAFRAŃSKA. *Nauki Przyr. (Lub.)* 2018 nr 4 (22) s. 89-97, il. bibliogr. streszcz. sum.	0,000	2,00
	Suma:	0,000	27,00

2. Monografie naukowe

2.1 Autorstwo rozdziału w monografii naukowej

Lp	Opis bibliograficzny	Pkt. MNiSW
1.	**Bakterie wykorzystywane w celu tworzenia, biofunkcyjnych i prozdrowotnych produktów mlecznych (Bacteria and yeast used to create biofunctional and health-promoting dairy foods).** [AUT.] JAGODA SZAFRAŃSKA, JAN MAŁECKI, EWA HABZA-KOWALSKA. W: Żywność i żywienie / Redakcja naukowa Jędrzej Nyćkowiak, Jacek Leśny Poznań 2020, Młodzi Naukowcy, s. 98-104, il. bibliogr. streszcz. 978-83-66392-82-3	5.00
2.	**Charakterystyka enzymu peroksydazy tyroidowej (TPO), wpływ stresu oksydacyjnego na jegofunkcjonowanie oraz zastosowanie metody izobolograficznej do obrazowania interakcji pomiędzy składnikami aktywnymi żywności na jego obniżenie(Characterization of the thyroid peroxidase enzyme (TPO), the impact of oxidative stress on its functioning and the use of the isobolographic method to visualize the interaction between active ingredients of food to reduce the oxidative**	5.00

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stress). [AUT.] EWA HABZA-KOWALSKA, JAGODA SZAFRAŃSKA. W: Żywność i żywienie / Redakcja naukowa Jędrzej Nyćkowiak, Jacek Leśny Poznań 2020, Młodzi Naukowcy, s. 49-53, il. bibliogr. streszcz, 978-83-66392-59-5

3.	**Rola oraz sposoby implementacji błonników w przemyśle spożywczym(The role and methods of fibers implementation in the food industry).** [AUT.] JAN MAŁECKI, JAGODA SZAFRAŃSKA. W: Żywność i żywienie / Redakcja naukowa Jędrzej Nyćkowiak, Jacek Leśny Poznań 2020, Młodzi Naukowcy, s. 72-77, il. bibliogr. streszcz, 978-83-66392-82-3.	5.00
4.	**Wpływ błonnika pokarmowego i jego składników na zdrowie człowieka(The effect of dietary fiber and its components on human health).** [AUT.] JAGODA SZAFRAŃSKA, JAN MAŁECKI. W: Żywność i żywienie / Redakcja naukowa Jędrzej Nyćkowiak, Jacek Leśny Poznań 2020, Młodzi Naukowcy, s. 91-97, il. bibliogr. streszcz, 978-83-66392-82-3.	5.00
5.	**Bakteriocyny w przemyśle mleczarskim(Bacteriocins in dairy industry).** [AUT.] JAGODA SZAFRAŃSKA, MACIEJ NASTAJ, EWA HABZA-KOWALSKA, ILONA MAZURKIEWICZ. W: Żywność i żywienie / Redakcja naukowa Marcin Baran, Jędrzej Nyćkowiak Poznań 2019, Młodzi Naukowcy, s. 89-95, il. bibliogr. streszcz, 978-83-66139-99-2.	5,00
6.	**Charakterystyka enzymów prozapalnych: lipooksygenazy (LOX), cyklooksygenazy (COX) i oksydazy ksantynowej (XO) oraz rola fitozwiązków jako potencjalnych inhibitorów tych enzymów.** [AUT.] EWA HABZA-KOWALSKA, JAGODA SZAFRAŃSKA, JUSTYNA BOCHNAK, ILONA MAZURKIEWICZ. W: Nauki przyrodnicze Część I : Fauna i flora / red. nauk. Marcin Baran, Jędrzej Nyćkowiak, UPP Poznań 2019, Młodzi Naukowcy, s. 40-44, il. bibliogr. streszcz, 978-83-66392-02-1.	5,00
7.	**Hydrokoloidy jako dodatki teksturotwórcze(Hydrocolloids as textural additives).** [AUT.] JAGODA SZAFRAŃSKA, BARTOSZ SOŁOWIEJ, EWA HABZA-KOWALSKA, ILONA MAZURKIEWICZ. W: Żywność i żywienie / Redakcja naukowa Marcin Baran, Jędrzej Nyćkowiak Poznań 2019, Młodzi Naukowcy, s. 83-88, il. bibliogr. streszcz, 978-83-66139-99-2.	5,00
8.	**Analiza fizykochemiczna i organoleptyczna produktów seropodobnych(Physicochemical and organoleptic analysis of cheese - like products).** [AUT.] KAMIL TOCZEK, MACIEJ NASTAJ, JAGODA SZAFRAŃSKA, BARTOSZ SOŁOWIEJ. W: Żywienie i żywność. Część I / [Redakcja naukowa Marcin Baran, Jędrzej Nyćkowiak] Poznań 2018, Młodzi Naukowcy, s. 137-143, il. bibliogr, 978-83-65917-97-3.	5,00
9.	**Białkowo-polifenolowe cząsteczki i ich rola w zapewnianiu funkcjonalności strukturalnej i zdrowotnej żywności(Protein-polyphenol molecules and their role in providing structural and health functionality of food).** [AUT.] EWA HABZA, JAGODA SZAFRAŃSKA. W: Nauki medyczne i nauki o zdrowiu Część IV – Farmacja Poznań 2018, Młodzi Naukowcy, s. 26-31, il. bibliogr, 978-83-66139-22-0.	5,00

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11. **Hydrokoloidy jako dodatki teksturotwórcze.** [AUT.] JAGODA SZAFRAŃSKA. W: Badania i rozwój młodych naukowców w Polsce 2018. Materiały konferencyjne-jesień. Część trzecia-Lublin / Red.nauk.Jędrzej Nyćkowiak,Jacek Leśny s.126. Poznań 2018, Młodzi Naukowcy.
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4.2. Publikacje popularnonaukowe

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- Wskaźnik Impact Factor dla publikacji z lat 2020-2021 został podany na podstawie JCR ed. 2019 r.
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