Dyscyplina naukowa: technologia żywności i żywienia

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*Rozprawa doktorska*

**Sól w produktach zbożowych jako źródło sodu w diecie dzieci**

***Salt in cereal products as a source of sodium in children's diets***

Rozprawa doktorska wykonana w Instytucie Żywienia Zwierząt i Bromatologii

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Niniejsza rozprawa doktorska jest oparta na cyklu publikacji naukowych, w którym pierwsza (P1) stanowi przegląd aktualnego stanu wiedzy na temat zawartości sodu i soli w produktach spożywczych i stanowi uzupełnienie teoretyczne dla cyklu badań eksperymentalnych realizowanych w ramach kolejnych prac (P2, P3, P4, P5, P6).

**P1. Jachimowicz-Rogowska K.**, Winiarska-Mieczan A. (2023). Initiatives to reduce the content of sodium in food products and meals and improve the population's health. *Nutrients*, 15(10), 2393; doi: 10.3390/nu15102393

Liczba punktów w roku publikacji: **MNiSW = 140; IF = 5,9**

**P2. Jachimowicz K.**, Winiarska-Mieczan A., Baranowska-Wójcik E., Bąkowski M. (2021). Pasta as a source of minerals in the diets of Poles; effect of culinary processing of pasta on the content of minerals. *Foods*, 10(9), 2131; doi: 10.3390/foods10092131

Liczba punktów w roku publikacji: **MNiSW = 100; IF = 5,561**

**P3. Jachimowicz-Rogowska K.**, Winiarska A., Szwajgier D., Baranowska-Wójcik E. (2025). The effect of pasta cooking method (unsalted versus salted water) on sodium absorption: an *in vitro* digestion study. *International Journal of Food Science & Technology*, 60(2), vvaf134; doi: 10.1093/ijfood/vvaf134

Liczba punktów w roku publikacji: **MNiSW = 70; IF = 3,1**

**P4. Jachimowicz-Rogowska K.**, Winiarska A. Czernecki T. (2025). Bread consumed in recommended portions does not provide excessive amounts of sodium and salt in children's diet. *Scientific Reports*, 15, 20638; doi: 10.1038/s41598-025-06824-x

Liczba punktów w roku publikacji: **MNiSW = 140; IF = 3,9**

**P5. Jachimowicz-Rogowska K.**, Winiarska A., Dobosz A., Czernecki T. (2025). Sweet-tasting cereal products as a source of sodium and salt in children's diets. *Food Additives & Contaminants: Part A*, 1–11. Advance online publication; doi: 10.1080/19440049.2025.2587215

Liczba punktów w roku publikacji: **MNiSW = 70; IF = 2,2**

**P6. Jachimowicz-Rogowska K.**, Winiarska-Mieczan A., Kwiecień M. (2023). Milk slices as a source of macroelements and microelements in the diet of pre-schoolers. *Journal of Elementology*, 28(2), 349–361; doi: 10.5601/jelem.2023.28.2.2371

Liczba punktów w roku publikacji: **MNiSW = 140; IF = 0,8**

**Sumaryczna liczba punktów za publikacje stanowiące przedmiot rozprawy doktorskiej według komunikatu MNiSW obowiązującego w roku wydania pracy: 660.**
**Łączny Impact Factor (IF) (zgodnie z rokiem opublikowania): 21,461.**

# Spis treści

# Streszczenie

Produkty zbożowe są powszechnym elementem diety dzieci. Znaczące spożycie sodu pochodzącego z produktów zbożowych, do których dodaje się sól na etapie produkcji, dotyczy większości populacji, w tym również najmłodszych. Nadmierne spożycie sodu ma poważne konsekwencje zdrowotne, takie jak nadciśnienie tętnicze, otyłość, rak żołądka. Celem pracy była analiza wybranych produktów zbożowych pod kątem zawartości sodu i soli oraz ocena ich udziału w pokryciu wystarczającego spożycia (*adquate intake*) sodu w diecie dzieci. Zawartość sodu określono za pomocą spektrometrii emisyjnej z plazmą indukcyjnie sprzężoną (ICP-OES), a wyniki przeliczone na porcję produktu odniesiono do poziomów wystarczającego spożycia dla dzieci z odpowiednich grup wiekowych. W ramach przeprowadzonych badań wykonano również symulacje trawienia *in vitro* makaronów ugotowanych z dodatkiem soli lub bez dodatku soli. Uzyskane wyniki potwierdziły, że sól w produktach zbożowych, zarówno dodawana na etapie produkcji, jak i podczas gotowania, stanowi istotne źródło sodu w diecie dzieci. Głównym źródłem sodu w diecie dzieci spośród analizowanych produktów zbożowych był chleb, ale również wyroby cukiernicze i piekarnicze. Chociaż pozostałe analizowane słodkie produkty zbożowe nie stanowiły znaczącego udziału w podaży sodu, to spożywane z innymi produktami bogatymi w sód oraz jedzone w nadmiernych ilościach, również mogą przyczyniać się do nadmiernego pobrania sodu. W pracy wykazano, że dodatek soli do wody w której gotuje się makaron istotnie zwiększa zawartość sodu w ugotowanym makaronie i pobranie sodu z porcją produktu, a płukanie makaronu po ugotowaniu zmniejsza zawartość sodu, ale nie do poziomu sprzed posolenia. Zaobserwowano również fakt, że gotowanie makaronu w osolonej wodzie ma znaczący wpływ na zwiększenie wchłaniania sodu w modelu przewodu pokarmowego *in vitro*, a procent wchłaniania sodu z makaronu jest dodatnio skorelowany z zawartością sodu w produkcie. Podsumowując, ze względu na globalne nadmierne spożycie soli przez dzieci, konieczne są różnorodne formy edukacji żywieniowej, takie jak nauka czytania etykiet produktów spożywczych oraz zachęcanie do redukcji dosalania. Z punktu widzenia technologii żywności, najważniejszą i najłatwiejszą do wprowadzenia zmianą jest zmniejszenie zawartości soli w chlebie i wypiekach. Należy zachęcać dzieci do spożywania przekąsek o niskim stopniu przetworzenia, najlepiej pełnoziarnistych, które dostarczają młodym organizmom więcej wartości odżywczych, jednocześnie utrzymując niską podaż sodu.

**Słowa kluczowe:** produkty zbożowe, sód, sól, wchłanianie sodu, żywienie dzieci

# Abstract

Cereal products are a common component of children's diets. Significant sodium intake from cereal products, which are salted during production, affects most of the population, including the youngest. Excessive sodium consumption has serious health consequences, such as hypertension, obesity, and stomach cancer. The aim of this study was to analyze selected cereal products for their sodium and salt content and assess their contribution to meeting adequate sodium intake in children's diets. Sodium content was determined using inductively coupled plasma emission spectrometry (ICP-OES), and the results per serving were compared to adequate intake levels for children in the appropriate age groups. The study also included *in vitro* simulations of the digestion of cooked pasta with and without added salt. The results confirmed that salt in cereal products, both added during production and cooking, is a significant source of sodium in children's diets. Among the cereal products analyzed, the main source of sodium in children's diets is bread, but also confectionery and bakery products. Although the other sweet cereal products analyzed do not contribute significantly to sodium intake, when consumed with other sodium-rich foods and in excessive quantities, they can also contribute to excess sodium intake. The study demonstrated that adding salt to the water used to cook pasta significantly increases the sodium content of cooked pasta and the sodium intake per serving. Rinsing the pasta after cooking reduces the sodium content, but not to the pre-salting level. Cooking pasta in salted water significantly increase sodium absorption in an *in vitro* gastrointestinal model, and the percentage of sodium absorption from pasta was positively correlated with the sodium content of the product. In summary, due to the global excess salt intake among children, various forms of nutritional education are necessary, such as teaching children to read food labels and encouraging them to reduce salting. From a food technology perspective, the most important and easiest change to implement is reducing the salt content in bread and baked goods. Children should be encouraged to eat minimally processed snacks, preferably whole grains, which provide young bodies with more nutrients while maintaining a low sodium intake.


**Keywords:** cereal products, sodium, salt, sodium absorption, child nutrition

# 1. Wprowadzenie teoretyczne na podstawie publikacji

## 1.1. Sól i sód – funkcje fizjologiczne, funkcje technologiczne, nadmiar i niedobór sodu, odczuwanie smaku

Sól (sól kuchenna, chlorek sodu, NaCl) składa się z jonów sodu ($Na^+$) i chlorku ($Cl^-$) (Strohm i in. 2016). Sód jest niezbędnym składnikiem pokarmowym, który odgrywa kluczową rolę w różnych funkcjach fizjologicznych, w szczególności w utrzymaniu równowagi wodno-elektrolitowej, równowagi kwasowo-zasadowej oraz funkcjonowaniu układu nerwowego (przewodzenie impulsów nerwowych) i mięśni. Ponadto sód jest składnikiem kwasu solnego w żołądku (Farquhar i in. 2015). Chlorek sodu odgrywa istotną rolę w przetwórstwie spożywczym, pełniąc kilka funkcji, takich jak: sensoryczna (kształtowanie smaku), teksturotwórcza (wpływająca na zdolność wiązania wody/tłuszczu) oraz bakteriostatyczna (hamująca rozwój mikroorganizmów) (Tobin i in. 2013). Ponieważ sól jest powszechnie dodawana do różnych produktów i potraw, niedobór sodu w diecie występuje bardzo rzadko. Natomiast znacznie częstszym problemem jest nadmierne spożycie sodu (Cheng i in. 2022; Pyka i in. 2019). Obserwacje sugerują, że sód jest składnikiem pokarmowym, na który można spojrzeć dwojako – z jednej strony jego przydatność w przygotowywaniu i przetwarzaniu żywności wydaje się być ważna, z drugiej strony istnieją znaczące zagrożenia zdrowotne wynikające z jego nadmiernego spożycia (Tremblay i in. 2024). Ograniczenie spożycia sodu stanowi wyzwanie dla ogółu społeczeństwa. Według Wang i in. (2023) aż 1,7–1,8 miliona zgonów z powodu chorób układu krążenia zanotowanych w latach 1990–2019 było związanych z wysokim spożyciem sodu, a problem jest wciąż aktualny. Innymi zdrowotnymi konsekwencjami długotrwałego nadmiernego spożycia sodu są:

- rak żołądka,
- otyłość,
- osteoporoza,
- zwiększona objętość płynów pozakomórkowych,
- obrzęki,
- przewlekła niewydolność nerek,
- wyższa ogólna śmiertelność.

Ograniczenie spożycia sodu jest jednym z najbardziej opłacalnych sposobów poprawy zdrowia i zmniejszenia obciążenia chorobami niezakaźnymi (Trieu i in. 2024; Surma i in. 2020; Rust i Ekmekcioglu, 2017; WHO, 2012).

Wykrywanie soli przez zmysł smaku ma fundamentalne znaczenie dla spożycia soli i homeostazy tkankowej (Liman, 2020). Komórki smakowe odpowiedzialne za odczuwanie smaku słonego, które potocznie nazywa się komórkami sodowymi, występują wyłącznie w kubkach smakowych brodawek grzybkowych przedniej części języka i są one przeznaczone wyłącznie do odczuwania tego smaku. Kanał sodowy wrażliwy na amiloryd jest czujnikiem jonów sodu w komórkach smakowych, pośredniczącym w przyciąganiu soli sodowych. Identyfikacja mechanizmów leżących u podstaw atrakcyjnego dla człowieka smaku sodu może pomóc opracować strategie skutkujące zmniejszeniem spożycia soli (Nomura i in. 2020).

## 1.2. Sól w produktach zbożowych

Produkty zbożowe mają istotny udział w codziennej diecie człowieka, są jednymi z najczęściej spożywanych artykułów żywieniowych przez większość światowej populacji. Produkty pełnoziarniste są ważnym źródłem składników mineralnych oraz błonnika pokarmowego, który ma korzystny wpływ na metabolizm lipidów i węglowodanów, a także regulację pracy przewodu pokarmowego, dlatego pełne ziarno powinno być stałym elementem diety (Reynolds i in. 2019; Winiarska-Mieczan i in. 2019a,b; Winiarska-Mieczan i in. 2018; Papanikolaou i Fulgoni, 2017).

Według Światowej Organizacji Zdrowia (WHO, World Health Organisation), w wielu krajach o wysokim dochodzie, a coraz częściej również w krajach o niskim i średnim dochodzie, znaczna część sodu w diecie pochodzi z przetworzonej żywności, takiej jak kolejno: pieczywo, płatki zbożowe i inne produkty zbożowe, przetworzone mięso oraz produkty mleczne (WHO, 2023a).

Chociaż tendencje żywieniowe różnią się na całym świecie, nadmierne spożycie sodu pochodzącego z produktów zbożowych, do których dodaje się sól na etapie produkcji, dotyczy większości populacji, w tym niestety również dzieci. Chleb i wyroby piekarnicze stanowią 34,9–41,1% udział w całodziennym spożyciu soli w Stanach Zjednoczonych, Hiszpanii i Polsce – populacje z wymienionych krajów zostały zidentyfikowane jako spożywające największe ilości soli właśnie z pieczywa (Bhat i in. 2020). Z kolei najwyższą średnią zawartość sodu w chlebie obserwuje się w Irlandii (1,68%), Polsce (1,64%) i Niemczech (1,6%), a Komisja Europejska zaleca 1,0-1,2% zawartość (Łazarczyk i in. 2016; FSAI, 2015; CVUA, 2015; Komisja Europejska, 2014). Wyroby piekarnicze stanowią ważne źródło sodu, ponieważ większość światowej populacji spożywa je w dużych ilościach (Zhang i in. 2017; Nowson i in. 2014). Badanie ankietowe analizujące spożycie chleba przez dzieci wykazało, że dzieci z grupy wiekowej 11–14 lat konsumowały średnio mniejsze niż rekomendowane ilości chleba (44 g vs 80 g), zaś dzieci z grupy wiekowej 1–3 lat – większe (31 g vs 20 g) (Jachimowicz-Rogowska i Winiarska, 2026). Pomimo wielu pozytywnych aspektów należy pamiętać, że chleb, szczególnie z rafinowanych ziaren, spożywany w nadmiarze może przyczyniać się do nadmiernej podaży energii i w efekcie zwiększania masy ciała (Lim i in. 2021), a spożywany wraz z innymi produktami, które dostarczają znacznej ilości soli (wędliny, sery podpuszczkowe, smarowidła itp.) zwiększać jej podaż w diecie (Papanikolaou i Fulgoni, 2019). Produkty zbożowe stanowią największy udział w całodziennym spożyciu soli między innymi na Łotwie i w Szwajcarii (populacja dzieci) oraz w Niemczech, w Polsce i w Stanach Zjednoczonych (populacja dorosłych) (USDA, 2020; Leite i Kunkulberga, 2018; Rios-Leyvraz i in. 2018; Strohm i in. 2016; Łazarczyk i in. 2016).

W suchych wyrobach piekarniczych (np. ciastka, krakersy, niektóre batoniki) jako środek spulchniający stosuje się wodorowęglan amonu ($NH_4HCO_3$). Kiedy opisano, że sprzyja on powstawaniu akrylamidu w słodkich wyrobach piekarniczych, zaczęto szukać alternatyw. Przemysł rekomenduje zastąpienie $NH_4HCO_3$ kombinacją spulchniaczy sodowych (np. $NaHCO_3$, wodorowęglan sodu) (Marianelli i in. 2025). Jednak strategia ta ma kompromisowy efekt – zastąpienie spulchniacza amonowego solą sodową zdecydowanie obniża zawartość akrylamidu, ale może zwiększyć zawartość sodu w produkcie, szczególnie jeśli użyje się więcej soli sodowej jako zamiennika (USDA, 2025; Lo Faro i in. 2022; Sarion i in. 2021; Mesías i in. 2019). Z tego powodu przy ocenie źródeł sodu w wyrobach piekarniczych należy rozważyć możliwe modyfikacje receptury stosowane przez producentów w odpowiedzi na wymogi redukcji akrylamidu (Komisja Europejska, 2017). Inne alternatywy, takie jak środki wapniowe/dwuwartościowe lub enzym asparaginaza nie wpływają na zawartość sodu w produktach zbożowych i cukierniczych (FDA, 2021; Rannou i in. 2016). Zmiany technologiczne związane z redukcją akrylamidu są źródłem podwyższenia poziomu sodu i stanowią istotny kontekst interpretacyjny, jednak nie można ostatecznie przypisać tego wzrostu wyłącznie zastąpieniu $NH_4HCO_3$ przez spulchniacze sodowe.

WHO od wielu lat promuje zmniejszenie spożycia soli jako najlepszą strategię mającą na celu ograniczenie chorób przewlekłych, a państwa członkowskie zatwierdziły w 2020 roku cel 30-procentowej redukcji średniego spożycia soli do 2025 roku (WHO, 2020). Jednak ostatni raport WHO dotyczący ograniczenia spożycia sodu pokazuje, że kraje członkowskie nie są na dobrej drodze do osiągnięcia globalnego celu, jakim jest planowane ograniczenie spożycia sodu – dotychczas zaledwie 5% państw członkowskich WHO wprowadziło obowiązkowe i kompleksowe strategie. W związku z tym rozważa się przedłużenie terminu realizacji celu do 2030 roku. Szacuje się, że jeśli kraje wdrożą politykę sugerowaną przez WHO, do 2030 roku na całym świecie można będzie zapobiec 7 milionom zgonów z powodu chorób układu krążenia. Odpowiada to 3,1% spadkowi zgonów z powodu tych chorób na całym świecie (WHO, 2023a).

## 1.3. Sól w żywieniu dzieci, w tym zalecenia i normy

W kontekście żywienia dzieci często porusza się kwestię szkodliwości nadmiaru cukru (Nguyen i in. 2023; Chang i in. 2021; Sekkarie i in. 2021). Pomija się natomiast temat nadmiaru soli. Dlatego niezwykle istotne jest wskazywanie rodzicom najważniejszych źródeł soli i sodu w diecie dzieci, przede wszystkim z nieoczywistych źródeł.

Gdy niemowlęta oswajają się ze słonym smakiem, stopniowo zaczynają go preferować. Podobnie jak w przypadku preferowania słodkiego smaku, dzieci preferują wyższe stężenia soli niż dorośli (Petty i in. 2020; Liem, 2017). Ponadto wysokie spożycie soli w dzieciństwie może przyczyniać się do rozwoju różnych chorób, takich jak nadciśnienie tętnicze w wieku dorosłym (Szajewska i in. 2021). Wyniki uzyskane przez Emmerik i in. (2020) pokazują, że wysokie spożycie sodu w ciągu pierwszych sześciu miesięcy po urodzeniu może wywoływać negatywne skutki dla zdrowia, takie jak podwyższone ciśnienie krwi. Badania epidemiologiczne wykazały występowanie nadciśnienia tętniczego u ponad 4% 6-latków, ponad 3% 9-latków i niemal 8% 14-latków (Song i in. 2019). Nadmiar soli może wpływać również niekorzystnie na prawidłowy rozwój układu kostnego dziecka, a także prowadzić do nadmiernego obciążenia nerek, które są słabiej rozwinięte niż u dorosłych (Mazzuca i in. 2024; Dinmukhamedova i in. 2019). W związku z tym zaleca się, o ile w ciągu pierwszego półrocza życia dziecka niemożliwe jest całkowite karmienie piersią, przygotowywanie mieszanek dla niemowląt przy użyciu wody źródlanej lub mineralnej o niskiej zawartości sodu, aby ograniczyć pobranie sodu z mlekiem (Emmerik i in. 2020). Starszym dzieciom zaleca się ograniczenie spożycia soli z przetworzonych produktów spożywczych, w tym słonych i słodkich przekąsek, oraz unikanie dodawania soli podczas przygotowywania posiłków (Szajewska i in. 2021; Liem, 2017). Należy zauważyć, że zalecenia dotyczące spożycia soli przez dzieci opierają się na ekstrapolacji danych pochodzących z badań przeprowadzonych na dorosłych. Ponadto do tej pory nie wprowadzono rozróżnienia między zaleceniami dla zdrowych dzieci, a zaleceniami dla dzieci z otyłością i/lub nadciśnieniem tętniczym. Odkrycia ostatnich lat, które umożliwiły lepsze zrozumienie mechanizmów łączących spożycie soli, otyłość i nadciśnienie tętnicze, wskazują na potrzebę większej indywidualizacji zaleceń (Wójcik i Kozioł-Kozakowska, 2021).

Europejski Urząd ds. Bezpieczeństwa Żywności (EFSA, European Food Safety Authority) ustalił, że dzienne spożycie sodu w ilości 2 g (odpowiadające 5 g soli dziennie) jest bezpieczne i odpowiednie dla dorosłej populacji w Europie (EFSA, 2019). Zalecane przez WHO spożycie sodu również wynosi poniżej 2 gramów na dobę (WHO, 2023b). Zgodnie z aktualnymi Normami Żywienia dla populacji Polski, wystarczające spożycie (AI, adequate intake) sodu dla osób dorosłych wynosi 1500 mg dziennie, podobnie jak w Stanach Zjednoczonych, Kanadzie, Niemczech, Austrii, Szwajcarii, Francji i krajach skandynawskich (Rychlik i in. 2024). W przypadku dzieci wartości ustalone dla osób dorosłych powinny zostać proporcjonalnie obniżone, biorąc pod uwagę niższe spożycie energii w różnych grupach wiekowych (Tabela 1) (Rychlik i in. 2024; WHO, 2023b). Ilości te odnoszą się do całkowitego spożycia soli, w tym zarówno soli dodawanej podczas przygotowywania posiłków, jak i soli zawartej w przetworzonych produktach spożywczych. Należy zaznaczyć, że AI sodu nie jest idealnym poziomem, który należy osiągnąć, ale jest to maksymalna wartość i należałoby spożywać mniej.

**Tabela 1.** Wystarczające spożycie (AI) sodu wraz z obliczonym dziennym zalecanym spożyciem soli (sól = sód × 2,5) dla dzieci z różnych grup wiekowych (Rychlik i in. 2024; WHO, 2023a; Surma i in. 2020)

| **Grupa wiekowa** | **AI sodu (mg/d)** | **Sól (mg/d)** |
|---|---|---|
| 1–3 | 750 | 1875 |
| 4–6 | 1000 | 2500 |
| 7–9 | 1200 | 3000 |
| 10–12 | 1300 | 3250 |

Średnie spożycie sodu w dorosłej populacji (WHO, 2023b; Wang i in. 2023; Ma i in. 2022) i wśród dzieci (Malczyk i in. 2024; Rodrigues i in. 2023; Mohammadifard i in. 2021; Gowrishankar i in. 2020; Johnson i in. 2019) znacznie przekracza rekomendacje, co nie pozostawia wątpliwości co do pilnej potrzeby podjęcia działań w zakresie zdrowia publicznego.

W krajach o wysokim dochodzie, w tym w Polsce, nadmierne spożycie sodu pochodzi głównie, w 75–80%, z przetworzonej żywności i gotowych posiłków, 10–15% pochodzi z soli dodawanej podczas gotowania lub przyprawiania potraw na talerzu, a pozostałe 5–10% występuje naturalnie w produktach spożywczych stanowiących część diety, podczas gdy głównym źródłem soli w diecie wielu krajów o niskim i średnim dochodzie jest sól dodawana w domu podczas gotowania, przyprawiania lub konserwowania. Ograniczenie spożycia sodu wyłącznie poprzez unikanie dodawania soli do potraw i podczas gotowania w krajach wysokorozwiniętych może nie być szczególnie skuteczne, ponieważ większość sodu w diecie pochodzi z przetworzonej żywności, do której sól jest dodawana podczas produkcji (Hunter i in. 2022; Quader i in. 2017). Nie należy jednak zapominać o produktach zbożowych takich jak makaron, kasza, płatki czy ryż, które naturalnie zawierają niewielkie ilości sodu, ale gdy sól zostanie dodana do wody podczas ich gotowania, poziom sodu w gotowym do jedzenia produkcie może znacznie wzrosnąć. Efekt ten jest zależny również od czasu gotowania i tego, czy produkt jest płukany po ugotowaniu (Bianchi i in. 2019; Winiarska-Mieczan i in. 2016).

Odżywianie wpływa na dojrzewanie i prawidłowe funkcjonowanie wszystkich układów organizmu dziecka w całym okresie rozwoju. Nieprawidłowe odżywianie, w tym nieodpowiedni profil składników pokarmowych w diecie dziecka, prowadzi do zaburzeń stanu odżywienia i zwiększa ryzyko niedoborów pokarmowych (Jachimowicz-Rogowska i Winiarska, 2026). Weker i in. (2022) rekomendują dla dzieci w wieku 4–6 lat i 7–9 lat pięć porcji produktów skrobiowych dziennie, w tym cztery porcje produktów zbożowych. Zatem produkty zbożowe powinny być obecne w codziennej racji pokarmowej dzieci, jednak należy wybierać te o jak najlepszej jakości i o jak najprostszym składzie.

## 1.4. Wchłanianie sodu z przewodu pokarmowego

Przewód pokarmowy pełni zasadniczą rolę jako łącznik między organizmem a otoczeniem, z którego czerpane są kluczowe dla życia składniki pokarmowe (Helander i Fändriks, 2014). Jego podstawową funkcją jest trawienie i wchłanianie składników pokarmowych, mikroelementów i elektrolitów, utrzymanie homeostazy wodnej, translokacja frakcji antygenów wielokomórkowych oraz eliminacja patogenów (Bellmann i in. 2015). Istnieje niewiele badań, w których wykorzystuje się modele ludzkiego jelita *in vitro* do oceny wchłaniania i transportu składników pokarmowych w organizmie człowieka (Baranowska-Wójcik i in. 2022a,b; Minekus i in. 2014), chociaż mogłyby być bardziej powszechne, gdyż przeprowadzanie klinicznych badań z udziałem ludzi jest często kosztowne, wymaga dużych nakładów zasobów i budzi wątpliwości etyczne. W związku z tym do badań przesiewowych i tworzenia nowych hipotez można i powinno się stosować alternatywne metody *in vitro*, które pozwalają określić parametry końcowe (Minekus i in. 2014). Modele trawienia *in vitro* dostarczają informacji na temat strawności, wchłaniania, przemian chemicznych i strukturalnych oraz wzorców uwalniania składników żywności w jelitach człowieka, umożliwiając w ten sposób zrozumienie mechanizmów leżących u podstaw trawienia i wchłaniania (Ding i in. 2017). Bardziej popularne w badaniach naukowych jest stosowanie modeli symulowanego trawienia żołądkowo-jelitowego szczurów (Dufoo-Hurtado i in. 2021) lub myszy (Yu i in. 2024), niż ludzi.

Proces gotowania produktów zbożowych powoduje zmiany w ich składzie chemicznym, szczególnie w przypadku składników mineralnych, które są wysoce rozpuszczalne w wodzie (Bianchi i in. 2019). Pokarm, przechodząc przez różne części przewodu pokarmowego, w tym jamę ustną, żołądek, jelito cienkie i okrężnicę, ulega przemianom strukturalnym i fizykochemicznym (McClements i in. 2016). Enzymy trawienne i zmiany pH w tych odcinkach mogą potencjalnie wpływać na proces wchłaniania *in vivo* (Baranowska-Wójcik i in. 2022a; Bischoff i in. 2020). Badania w tej dziedzinie mogą pomóc w lepszym zrozumieniu związku między zawartością soli w produktach spożywczych a wchłanianiem sodu, co może wspierać opracowywanie strategii mających na celu ograniczenie spożycia soli kuchennej.

# 2. Hipoteza i cel badań

## 2.1. Hipoteza

Produkty zbożowe mogą być źródłem sodu w diecie dzieci, a spożywane w zbyt dużych ilościach mogą przyczynić się do spożycia nadmiernych ilości soli.

## 2.2. Cele badań

**Głównym celem** rozprawy doktorskiej była analiza wybranych produktów zbożowych pod kątem zawartości sodu i soli oraz ocena ich udziału w pokryciu wystarczającego spożycia sodu w diecie dzieci.

**Cele szczegółowe**:

1. Dokonanie analizy i oceny zawartości sodu w wybranych produktach zbożowych: makarony o różnym kształcie i składzie (gotowane w różnych warunkach), biszkopty z kremem mlecznym, chleby o różnym składzie, płatki śniadaniowe oraz słodkie produkty zbożowe tj. ciastka, ciastka dla niemowląt i małych dzieci, batony zbożowe, wafle ryżowe, wyroby cukiernicze i piekarnicze oraz odniesienie tych wartości do wystarczającego spożycia sodu dla dzieci i aktualnych wytycznych dla tej populacji.
2. Przeprowadzenie symulacji trawienia żołądkowo-jelitowego *in vitro* w celu określenia stopnia wchłaniania sodu z pięciu różnych rodzajów makaronu fusilli różniących się składem, z dodatkiem soli kuchennej podczas gotowania lub bez soli.

# 3. Materiały i metody

## 3.1. Materiały

Przegląd wiedzy (**P1**)

Wyszukiwanie artykułów zawężono do opublikowanych w ciągu ostatnich 10 lat. Na podstawie tytułów i streszczeń odrzucono artykuły niezwiązane z kryteriami merytorycznymi, a pozostałe prace oryginalne i przeglądowe poddano dogłębnej analizie w celu zidentyfikowania najbardziej trafnych publikacji. Ostatecznie przeanalizowano łącznie 343 publikacje, z czego wykorzystano 166 pozycji: 72 prace oryginalne oraz 94 prace przeglądowe i metaanalizy.

Obróbka kulinarna makaronów (**P2**)

Do analiz włączono próby makaronów (n = 35) o różnych kształtach (penne, ditalini, gigli, creste, fusilli, filini) i o różnym składzie (pszenne; pszenne pełnoziarniste; orkiszowe; z dodatkiem mąki jęczmiennej, amarantusowej, ryżowej, kukurydzianej, z tapioki; w głównej mierze z upraw konwencjonalnych i bezjajeczne), bez dodatku soli w suchym produkcie, zakupione w sklepach spożywczych na terenie miasta Lublin. Makaron gotowano *al dente* w wodzie (100 g makaronu na 1 l wody pitnej) z dodatkiem soli kuchennej (16 g soli/l) lub bez, zgodnie ze schematem:

NaCl + NR – gotowany z solą i niepłukany (ang. *not rinsed*);

NaCl + R – gotowany z solą i płukany pod bieżącą wodą pitną (ang. *rinsed*);

NR – gotowany bez soli i niepłukany;

R – gotowany bez soli i płukany pod bieżącą wodą pitną.

Czas gotowania był zgodny z zaleceniami producentów makaronu na opakowaniach. Po ugotowaniu makaron odsączono na plastikowych sitkach. Następnie każdą próbę podzielono na pół i jedną z części makaronu płukano pod bieżącą zimną wodą przez 10 sekund. Ugotowany makaron (zarówno płukany, jak i niepłukany) zważono ponownie po dwóch minutach. Przygotowany makaron umieszczono w suszarce w temperaturze 65°C na 24 godziny, następnie zmielono go w młynku elektrycznym wyposażonym w plastikowe noże. Zważono 3 g (z dokładnością do jednego miejsca po przecinku) każdej próby, w trzech powtórzeniach. Zmielone próby umieszczono pojedynczo w wyprażonych porcelanowych tyglach, które przechowywano przez jeden dzień w eksykatorze do czasu wykonania dalszych analiz.

Trawienie makaronów (**P3**)

Analizie poddano różne rodzaje makaronów fusilli (n = 5), różniące się składem recepturowym (pszenica durum; pszenica durum z algami morskimi; pełnoziarnisty pszenno-żytni; jajeczny; ryżowy ze skrobią kukurydzianą i tapioką). Zgodnie z deklaracjami producenta na opakowaniu, żaden z produktów nie zawierał soli. Z każdego rodzaju makaronu przygotowano próby o masie 100 g (zważone z dokładnością do jednego miejsca po przecinku) i ugotowano je przez czas zalecany przez producenta w wodzie pitnej bez dodatku soli lub z dodatkiem soli kuchennej w stężeniu 16 g/l. Po ugotowaniu makaron odsączono za pomocą plastikowego sitka. Po dwóch minutach odważono 100 g odsączonego makaronu i poddano go trawieniu *in vitro*.

Przygotowanie prób chleba (**P4**)

Przeanalizowano siedem rodzajów chleba (pszenny, żytni, pszenno-żytni, pszenny tostowy, pełnoziarnisty tostowy, graham, orkiszowy) w 10 próbach każdego rodzaju (n = 70) oraz cztery rodzaje mąki chlebowej (pszenna typu 750, pełnoziarnista pszenna typu 2000, żytnia, orkiszowa) w 10 próbach każdego rodzaju (n = 40) zakupionych na terenie miasta Lublin. Próby chleba i mąki umieszczono w suszarce w temperaturze 65°C na 24 godziny. Następnie próby chleba zmielono w młynku elektrycznym wyposażonym w plastikowe noże i zważono 3 g (z dokładnością do jednego miejsca po przecinku) każdej próby chleba i mąki, w dwóch powtórzeniach. Próby chleba obejmowały zarówno miąższ, jak i skórkę wyciętą z kromki o grubości dwóch centymetrów. Zmielone próby umieszczono pojedynczo w wyprażonych porcelanowych tyglach, które przechowywano przez jeden dzień w eksykatorze do czasu wykonania dalszych analiz.

Przygotowanie prób słodkich produktów zbożowych (**P5**)

Wybrane słodkie produkty zbożowe (płatki śniadaniowe n = 38, pieczywo cukiernicze n = 78, ciastka n = 31, ciastka dla niemowląt i małych dzieci n = 10, batony zbożowe n = 47, wafle ryżowe n = 10) zakupiono w ogólnodostępnych sklepach spożywczych na terenie miasta Lublin. Produkty umieszczono w suszarce w temperaturze 65°C na 24 godziny. Każdą próbę zmielono w młynku elektrycznym zaopatrzonym w plastikowe ostrza i zważono 3 g (z dokładnością do jednego miejsca po przecinku) każdej próby w trzech powtórzeniach. Zmielone próby umieszczono pojedynczo w wyprażonych porcelanowych tyglach, które przechowywano przez jeden dzień w eksykatorze do czasu wykonania dalszych analiz.

Przygotowanie prób biszkoptów z mlecznym nadzieniem (**P6**)

Analizie poddano różne biszkopty z mlecznym nadzieniem (n = 15), tzw. mleczne kanapki, ogólnodostępne i zakupione w sklepach spożywczych na terenie miasta Lublin. Produkty umieszczono w suszarce w temperaturze 65°C na 24 godziny. Każdą próbę zmielono w młynku elektrycznym zaopatrzonym w plastikowe ostrza i zważono 3 g (z dokładnością do jednego miejsca po przecinku) każdej próby w trzech powtórzeniach. Zmielone próby umieszczono pojedynczo w wyprażonych porcelanowych tyglach, które przechowywano przez jeden dzień w eksykatorze do czasu wykonania dalszych analiz.

## 3.2. Metody

### 3.2.1. Analizy chemiczne

Materiał badany, w którym miał zostać oznaczony sód (**P2, P3, P4, P5, P6**), był analizowany w ten sam sposób dla wszystkich prób. Wysuszone próby zmineralizowano w piecu muflowym (temperatura 550°C, 12 h, przeciwutleniacz – nadtlenek wodoru). Popiół uzyskany w wyniku mineralizacji rozpuszczono w 10 ml 1M kwasu azotowego ($HNO_3$). Zawartość sodu określono za pomocą ICP-OES (spektrometrów emisyjnych z plazmą indukcyjnie sprzężoną) przy użyciu spektrometru 720-ES (Varian, Palo Alto, CA, USA). Warunki pracy dla ICP-OES były następujące: moc generatora RF – 1,2 kW; szybkość przepływu gazu plazmowego – 15,0 l/min; szybkość przepływu gazu pomocniczego – 2,25 l/min; szybkość przepływu gazu nebulizatora – 0,70 l/min; szybkość przepływu próbki – 0,1 ml/min; powtórzenia – 4; czas odczytu – 15 s; prędkość obrotowa pompy perystaltycznej – 12 obr./min; parametry oznaczania: długość fali – 589,592 nm, LOD (granica wykrywalności) – 0,25 mg/kg i LOQ (granica oznaczalności) – 0,39 mg/kg. Wartość graniczną wykrywalności (LOD) obliczono za pomocą wzoru CL = 3 Sb/m, gdzie „Sb" to odchylenie standardowe sześciu powtórzonych pomiarów zerowych, a „m" to wartość nachylenia krzywej kalibracyjnej (Pirsaheb i in. 2015). Do narysowania krzywej kalibracyjnej wykorzystano standardy LCG do przygotowania roztworów mineralnych o stężeniach 1, 2, 4 i 8 μg / 1 l. Dokładność wyników potwierdzono przy użyciu 1M $HNO_3$ i dwóch próbek referencyjnych: paszy dla drobiu LGC 7173 i pszenicy NCS ZC 73009.

Stopień odzysku sodu wynosił 94%. Wszystkie analizy przeprowadzono w dwóch (**P4**), trzech (**P2, P5, P6**) lub czterech (**P3**) powtórzeniach.

### 3.2.2. Odczynniki

Roztwory przygotowano przy użyciu wody dejonizowanej (Hydrolab Deioniser, Gdańsk, Polska) i ultraczystych odczynników chemicznych. Nadtlenek wodoru (30% czystości) i $HNO_3$ (65% ultraczystości) zakupiono w firmie POCH S.A. (Lublin, Polska). Roztwór wzorcowy Na (1000 mg $L^{-1}$, czystość 99,99%) zakupiono w firmie LGC Standards Sp. z.o.o. (Kiełpin, Polska). Do sprawdzenia jakości wykorzystano certyfikowany materiał odniesienia.

(1) Pasza dla drobiu LGC 7173 (LGC Standards GmbH, Wesel, Niemcy) zawierała 1180 mg Na / 1 kg.

(2) Pszenica NCS ZC 73009 (National Institute of Standard and Technology, Gaithersburg, MD, USA) zawierała 17,0 mg Na / 1 kg.

### 3.2.3. Obliczenia

Współczynnik retencji (%) sodu z makaronów (**P2**) obliczono na podstawie wzoru:

$$Retencja\ (\%) = \frac{zawarto\acute{s}\acute{c}\ sodu\ w\ ugotowanym\ makaronie\ (g) \times masa\ makaronu\ po\ gotowaniu\ (g)}{zawarto\acute{s}\acute{c}\ sodu\ w\ surowym\ makaronie\ (g)\ \times masa\ makaronu\ przed\ gotowaniem\ (g)} \times 100$$

Na podstawie średniej zawartości sodu w ugotowanym makaronie (**P2**), przeliczono ją na 1 porcję makaronu, zakładając, że porcja wynosi 50 g dla dzieci w wieku 1–3 lat, 60 g dla dzieci w wieku 4–6 lat, 100 g dla dzieci w wieku 7–12 lat, 125 g dla dzieci w wieku 13–15 lat i 135 g dla młodzieży w wieku 16–18 lat (Weker i Barańska, 2015; Szponar i Dzieniszewski, 2001; Weker, 2014; Jarosz, 2008). Średni udział makaronu (**P2**), chleba (**P4**), słodkich produktów zbożowych (**P5**) i biszkoptów z mlecznym nadzieniem (**P6**) w referencyjnym dziennym spożyciu sodu obliczono na podstawie wzoru:

$$Udzia\l\ w\ referencyjnym\ dziennym\ spo\dot{z}yciu\ sodu = \frac{dzienne\ spo\dot{z}ycie\ sodu\ (mg) \times 100}{referencyjne\ dzienne\ spo\dot{z}ycie\ sodu\ (mg)}$$

gdzie:

$$dzienne\ spo\dot{z}ycie\ sodu = dzienna\ porcja\ (g) \times \acute{s}rednia\ zawarto\acute{s}\acute{c}\ sodu\ w\ porcji (mg)$$

Kromka chleba (**P4**) została przyjęta jako 30 g, czyli odpowiednik minimalnej spożywanej porcji chleba. Dodatkowo, zawartość sodu w chlebie podano również na 1000 g oraz na 1 porcję w odniesieniu do wieku dzieci. Zawartość sodu oraz soli w słodkich produktach zbożowych (**P5**) zostały przedstawione w 1000 g oraz w 1 porcji produktu. Zawartość sodu w biszkoptach z mlecznym nadzieniem (**P6**) podano w przeliczeniu na porcję produktu (zakres 16–50 g; średnio 31,7 g).

Spożycie sodu wraz z jedną porcją makaronu (**P2**), chleba (**P4**), słodkich produktów zbożowych (**P5**) i biszkoptów z mlecznym nadzieniem (**P6**) porównano z wartościami wystarczającego spożycia (AI) zawartymi w Normach żywienia dla populacji Polski (Rychlik i in. 2024): 750 mg dziennie dla dzieci w wieku 1–3 lat, 1000 mg dziennie dla dzieci w wieku 4–6 lat, 1200 mg dziennie dla dzieci w wieku 7–9 lat, 1300 mg dziennie dla dzieci w wieku 10–12 lat, 1500 mg dziennie dla młodzieży w wieku 13–15 lat i 16–18 lat.

Porównano zawartość sodu (mg/1000 g) w mące i pieczywie, aby wykazać, ile sodu pochodzi z soli dodawanej na etapie produkcji pieczywa, a ile z mąki (**P4**).

Na podstawie zawartości sodu w badanych produktach wyliczono zawartość soli, korzystając z wzoru:

$$sól = sód \times 2{,}5$$

### 3.2.4. Określenie ilości sodu obecnego w makaronie w procesie trawienia *in vitro*

Każdą próbę makaronu poddano symulacji trawienia *in vitro*. Cały proces obejmował fazę jamy ustnej, żołądka i jelita cienkiego. Do fazy jamy ustnej wprowadzono 100 g ugotowanego makaronu (przygotowanego w osolonej lub niesolonej wodzie) wraz z 100 ml płynu ślinowego. Zachowano wszelkie parametry odwzorowujące pracę przewodu pokarmowego (czas, objętość treści, temperatura, ruchy perystaltyczne, symulacja stopnia wchłaniania, wartości pH). Zastosowana membrana mikrofiltracyjna posłużyła do symulacji wchłaniania i ruchów perystaltycznych w modelu przewodu pokarmowego. Jednocześnie, w ten sam sposób, przeprowadzono dwie ślepe próby, zawierające płyn trawienny w wodzie dejonizowanej.

Znając ilość sodu w płynach ślinowych (podwójna ślepa próba) i biorąc pod uwagę, że całkowita objętość w fazie jamy ustnej wynosiła 200 ml (100 ml makaronu + 100 ml płynów ślinowych), obliczono ilość sodu w tej objętości i na podstawie tego określono procentowe uwalnianie sodu na każdym etapie trawienia.

### 3.2.5. Analiza statystyczna

Wyniki zostały przygotowane do opracowania statystycznego w programie Microsoft Excel 2010. Analizę statystyczną wykonano przy użyciu oprogramowania Statistica 13 (StatSoft, Kraków, Poland). Średnie wartości obliczono na podstawie dwóch (**P4**), trzech (**P2, P5, P6**) lub czterech (**P3**) powtórzeń dla każdej próby. Obliczono współczynnik korelacji Pearsona między zawartością sodu w ugotowanym makaronie, a procentowym wchłanianiem sodu w przewodzie pokarmowym w warunkach *in vitro* (**P3**). Statystycznie istotne różnice obliczono za pomocą: jednoczynnikowej analizy wariancji (ANOVA) z wykorzystaniem testu Duncana ($p<0,05$) (**P2, P5, P6**), testu HSD Tukeya ($p<0,0001$) (**P4**) oraz testu HSD Tukeya ($p<0,05$) (**P3**).

# 4. Omówienie wyników i dyskusja

## 4.1. Przedstawienie dotychczasowego stanu wiedzy dotyczącego strategii zmniejszania zawartości soli w żywności jako potencjalnie skutecznej metody poprawy stanu zdrowia społeczeństwa, w tym dzieci

W pracy przeglądowej **P1**, pt. *„Initiatives to reduce the content of sodium in food products and meals and improve the population's health"*, przedstawiono aktualny stan wiedzy dotyczący globalnych i krajowych działań zmierzających do redukcji zawartości sodu w żywności oraz ich znaczenia dla zdrowia publicznego. Wskazano, że nadmierne spożycie sodu stanowi powszechny problem żywieniowy, a jego skala jest ściśle związana z rosnącą dostępnością żywności przetworzonej oraz zmianami nawyków żywieniowych. Podkreślono, że sól pozostaje głównym źródłem sodu w diecie, natomiast jej spożycie w wielu krajach znacząco przekracza rekomendacje WHO, zalecającej ograniczenie dziennej podaży soli do 5 g (około 2 g sodu). Przytaczane dane epidemiologiczne wskazują, że spożycie soli w populacji dorosłych wynosi średnio 9–10 g dziennie, a wśród dzieci i młodzieży ok. 7–8 g, co znacznie zwiększa ryzyko rozwoju nadciśnienia tętniczego, chorób sercowo-naczyniowych oraz raka żołądka.

W publikacji szeroko omówiono inicjatywy mające na celu zmniejszenie zawartości sodu w diecie, obejmujące zarówno działania legislacyjne, technologiczne, jak i edukacyjne. Kluczowym elementem są działania reformulacyjne polegające na modyfikacji składu produktów spożywczych poprzez stopniowe zmniejszanie ilości dodawanej soli lub zastępowanie jej alternatywnymi składnikami wpływającymi na smakowitość i bezpieczeństwo produktu ($KCl$, $MgCl_2$, $CaCl_2$), w tym naturalnymi wzmacniaczami smaku i środkami przeciwdrobnoustrojowymi (zioła, przyprawy korzenne, ekstrakty roślinne, olejki eteryczne, algi, aminokwasy). Autorzy wskazują na skuteczność strategii polegającej na systematycznym obniżaniu zawartości sodu w produktach, która pozwala utrzymać akceptację sensoryczną. Istotnym narzędziem są również substytuty soli, oparte m.in. na chlorku potasu lub mieszankach mineralnych, które są obiecującą alternatywą, jednak niosą pewne ograniczenia technologiczne i sensoryczne, w tym możliwość występowania metalicznego posmaku lub oddziaływania na stabilność mikrobiologiczną żywności.

Zwrócono uwagę na szczególne znaczenie produktów zbożowych, zwłaszcza pieczywa, które w wielu krajach stanowi jedno z głównych źródeł sodu w diecie. W artykule podkreślono, że redukcja soli w pieczywie jest jedną z najbardziej efektywnych i technologicznie wykonalnych metod ograniczania dziennej podaży sodu na poziomie populacyjnym. W przytoczonych analizach wskazano, że samo pieczywo może pokrywać nawet blisko połowę dziennego spożycia sodu, co czyni je kluczowym elementem strategii zdrowia publicznego.

W pracy szczegółowo scharakteryzowano także działania edukacyjne skierowane do konsumentów, mające na celu wzrost świadomości żywieniowej oraz promowanie wyboru produktów o niższej zawartości soli. Podkreślono rolę czytelnego etykietowania produktów spożywczych, w tym zastosowania systemów *front-of-pack*, które ułatwiają szybką ocenę poziomu sodu w produkcie przez konsumenta.

Omówiono również działania regulacyjne i ekonomiczne, obejmujące m.in. wprowadzanie limitów sodu w określonych kategoriach produktów, programy dobrowolnych lub obowiązkowych reformulacji, a także potencjalne instrumenty fiskalne, takie jak opodatkowanie produktów o wysokiej zawartości sodu. Zwrócono uwagę, że skuteczność takich działań jest najwyższa wtedy, gdy łączą one presję regulacyjną, edukację społeczną oraz realne wsparcie technologiczne dla przemysłu spożywczego.

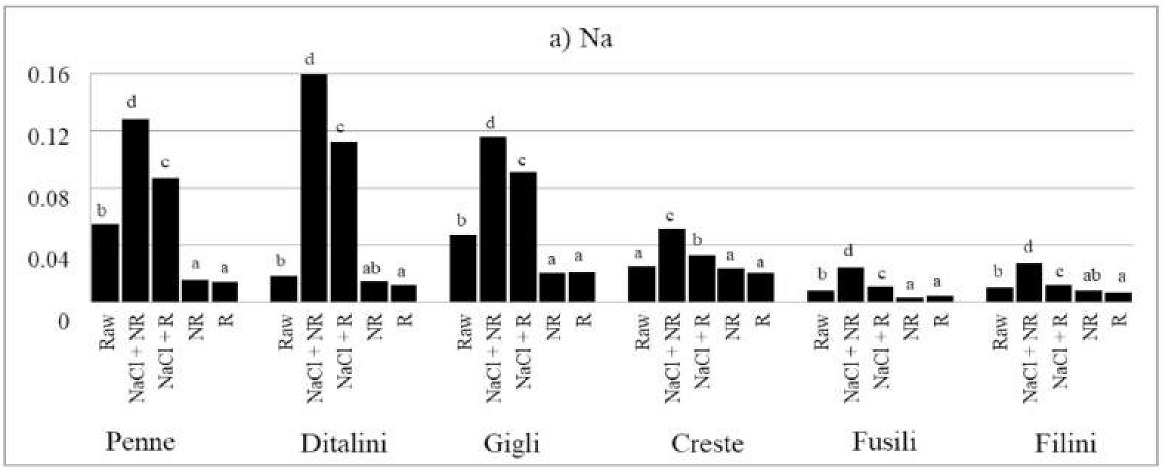
Podsumowując, w publikacji **P1** przedstawiono liczne wyzwania związane z redukcją poziomu sodu w żywności, w tym aspekty technologiczne (rola soli w utrzymaniu stabilności mikrobiologicznej i tekstury), sensoryczne (akceptacja smakowa konsumentów) oraz ekonomiczne (koszty reformulacji i wdrożenia nowych rozwiązań technologicznych). Podkreślono, że skuteczna redukcja podaży sodu wymaga podejścia wielosektorowego, angażującego producentów żywności, instytucje publiczne, specjalistów ds. żywienia oraz konsumentów. **Praca ta podkreśla, że kompleksowe wdrażanie inicjatyw w tym obszarze może znacząco zmniejszyć obciążenie chorobami związanymi z nadmiernym spożyciem soli, przyczyniając się do wydłużenia długości życia i poprawy ogólnego stanu zdrowia społeczeństwa.**

## 4.2. Ocena wpływu gotowania makaronu w wodzie z dodatkiem soli lub bez dodatku soli oraz płukanego lub niepłukanego po ugotowaniu na zawartość sodu oraz pobranie sodu przez dzieci i młodzież w wieku 1–18 lat

Makaron jest powszechnym, łatwym w przygotowaniu i przechowywaniu składnikiem diety (Kravęcka i in. 2022; Yaver i Bilgiçli, 2021; Pinel i in. 2025). Sposób jego obróbki kulinarnej, w tym użycie soli w wodzie do gotowania oraz płukanie makaronu po ugotowaniu może znacząco wpływać na zawartość sodu w produkcie finalnym (Bianchi i in. 2019; Jambrec i in. 2015). Celem pracy badawczej **P2**, pt. *„Pasta as a source of minerals in the diets of Poles; effect of culinary processing of pasta on the content of minerals"*, była ocena wpływu dwóch czynników kulinarnych: (1) dodania soli do wody podczas gotowania oraz (2) płukania makaronu po ugotowaniu, na zawartość sodu w ugotowanym makaronie. Dodatkowo, oszacowano wielkość pobrania sodu z porcji makaronu przez dzieci i młodzież z różnych grup wiekowych (1–18 lat) w populacji Polski.

### 4.2.1. Wpływ obróbki kulinarnej na zawartość sodu

Stwierdzono statystycznie istotny wpływ ($p<0{,}05$) soli dodawanej do wody, w której gotuje się makaron; płukania ugotowanego makaronu pod bieżącą wodą oraz kształtu makaronu na zawartość sodu (Wykres 1).




**Wykres 1.** Zawartość sodu (Na) w makaronie, g $kg^{-1}$ świeżej masy

Raw – surowy makaron; NaCl+NR – gotowany z solą i niepłukany; NaCl+R – gotowany z solą i płukany; NR – gotowany bez soli i niepłukany; R – gotowany bez soli i płukany; $^{a, b, c, d}$ – wartości z różnymi indeksami górnymi różnią się przy $p<0{,}05$ według testu Duncana

Ustalono, że w wariancie NaCl + NR (gotowany z solą, niepłukany) retencja sodu wynosiła w przybliżeniu 780% w porównaniu do makaronu surowego, natomiast w wariancie NaCl + R (z solą, płukany) retencja wynosiła około 300%. Co więcej, płukanie ugotowanego makaronu znacząco redukuje zawartość sodu: w wariancie NaCl + R zawartość sodu była o około 31% niższa niż w tej samej wersji bez płukania (NaCl + NR). Bianchi i in. (2019) uzyskali podobne wyniki, stwierdzając, że płukanie ugotowanego makaronu pod bieżącą wodą zmniejsza zawartość sodu o około 30% w odniesieniu do makaronu niepłukanego, posolonego. Zatem, chociaż płucząc po ugotowaniu makaron z dodatkiem soli eliminuje się część sodu, zabieg ten nie przywraca zawartości sodu porównywalnej z wariantem makaronu gotowanym bez soli.

Szersze analizy pokazały, że makaron gotowany w niesolonej wodzie (NR, R) zawierał mniej innych analizowanych w badaniu składników mineralnych (K, Ca, Mg, Zn, Cu, Fe i Mn) niż makaron surowy ($p<0,05$). Niezależnie od kształtu makaronu, gotowanie w osolonej wodzie (NaCl + NR, NaCl + R) spowodowało istotny wzrost ($p<0,05$) zawartość sodu i istotnie zmniejszyło ($p<0,05$) zawartość wszystkich pozostałych składników mineralnych w porównaniu z ich poziomem w surowym makaronie. Z kolei makaron gotowany w niesolonej wodzie zawierał mniej analizowanych składników mineralnych (oprócz K) niż makaron surowy, niezależnie od jego kształtu ($p<0,05$). Ponadto gotowanie makaronu w niesolonej wodzie spowodowało istotne zmniejszenie ($p<0,05$) zawartości sodu i istotne zwiększenie ($p<0,05$) poziomu innych składników mineralnych w porównaniu z makaronem gotowanym w osolonej wodzie.

W Tabeli 2 przedstawiono porównanie średniej procentowej zawartości sodu w makaronach gotowanych z dodatkiem soli lub bez soli oraz płukanych lub niepłukanych. Płukanie makaronu ugotowanego w niesolonej wodzie (R) zmniejszyło zawartość sodu o około 8% w porównaniu z makaronem niepłukanym (NR). Sól dodana do wody podczas gotowania makaronu zwiększyła zawartość sodu prawie 3,5-krotnie w przypadku makaronu płukanego (NaCl + R) i prawie 5-krotnie w przypadku makaronu niepłukanego (NaCl + NR) w porównaniu z makaronem gotowanym w niesolonej wodzie (NR). Bianchi i in. (2019) dodali różne ilości soli (0 g, 3,17 g, 6,34 g soli / litr wody) do wody używanej do gotowania makaronu, co spowodowało liniowy wzrost zawartości sodu w makaronie. W badaniu tym rezygnacja z dodatku soli do gotowania makaronu zmniejszyła zawartość sodu w ugotowanym makaronie o 48% w porównaniu z zawartością sodu w makaronie ugotowanym z dodatkiem 3,17 g soli i o 99% w porównaniu z zawartością sodu w makaronie ugotowanym z dodatkiem 6,34 g soli. Z kolei Jambrec i in. (2015) wykazali, że podczas gotowania makaronu w niesolonej wodzie zawartość sodu w produkcie zmniejsza się o około 42% w porównaniu z produktem surowym.

**Tabela 2.** Porównanie średniej zawartości sodu (Na) w makaronach gotowanych z dodatkiem soli lub bez soli, płukanych lub niepłukanych, %

| | **Na** |
|---|---|
| R vs. NaCl + R [1] | 344 |
| NR vs NaCl + NR [2] | 492 |
| NaCl + NR vs. NaCl + R [3] | -31.3 |
| NR vs. R [4] | -8.42 |

[1] Wartości dla gotowanych bez soli, płukanych (R) przyjęto jako 100%; [2] Wartości dla gotowanych bez soli, niepłukanych (NR) przyjęto jako 100%; [3] Wartości dla gotowanych z solą, niepłukanych (NaCl + NR) przyjęto jako 100%; [4] Wartości dla gotowanych bez soli, niepłukanych (NR) przyjęto jako 100 %.

### 4.2.2. Makaron jako źródło sodu w diecie dzieci

Dostarczana ilość sodu w jednej porcji makaronu ugotowanego w osolonej wodzie (NaCl + NR, NaCl + R) była wyższa ($p<0,05$) niż w jednej porcji makaronu ugotowanego w niesolonej wodzie (NR, R) dla wszystkich grup wiekowych. Zależność tę można przedstawić jako NaCl + NR > NaCl + R > NR = R. Jedna porcja makaronu pokrywała dzienne zapotrzebowanie na sód w diecie dzieci w wieku od 1 do 3 lat i od 4 do 6 lat – od 0,1% AI (NR, R) do 0,5% AI (NaCl + NR), w diecie dzieci w wieku od 7 do 12 lat – od 0,1% AI (NR, R) do 0,6% AI (NaCl + NR), a w diecie młodzieży w wieku od 13 do 15 lat i od 16 do 18 lat – od 0,1% AI (NR, R) do 0,7% AI (NaCl + NR) (Tabela 3).

**Tabela 3.** Średni udział porcji makaronu w dziennym wystarczającym spożyciu (AI) sodu (Na) w diecie dzieci z poszczególnych grup wiekowych, %

| grupa wiekowa | Na | grupa wiekowa | Na | grupa wiekowa | Na |
|---|---|---|---|---|---|
| **1–3** [2] | | **7–12** [4] | | **16–18** [6] | |
| NaCl+NR | 0.5 | NaCl+NR | 0.6 | NaCl+NR | 0.7 |
| NaCl+R | 0.4 | NaCl+R | 0.5 | NaCl+R | 0.5 |
| NR | 0.1 | NR | 0.1 | NR | 0.1 |
| R | 0.1 | R | 0.1 | R | 0.1 |
| **4–6** [3] | | **13–15** [5] | | | |
| NaCl+NR | 0.5 | NaCl+NR | 0.7 | | |
| NaCl+R | 0.3 | NaCl+R | 0.5 | | |
| NR | 0.1 | NR | 0.1 | | |
| R | 0.1 | R | 0.1 | | |

[1] na podstawie Rychlik i in. (2024); wielkość porcji: [2] dzieci 1–3 lat 50 g (Weker i Barańska, 2015), [3] dzieci 4–6 lat 60 g (Szponar i Dzieniszewski, 2001), [4] dzieci 7–12 lat 100 g (Weker, 2014), [5] młodzież 13–15 lat 125 g (Jarosz, 2008), [6] młodzież 16–18 lat 135 g (Jarosz, 2008); NaCl+NR – gotowany z solą i niepłukany; NaCl+R – gotowany z solą i płukany; NR – gotowany bez soli i niepłukany; R – gotowany bez soli i płukany.

Chociaż badanie nie wskazują na znaczący udział makaronu w dostarczaniu sodu (mniej niż 1% AI sodu dla wszystkich analizowanych grup wiekowych), można zaobserwować znaczący wpływ dodawania soli do wody podczas gotowania na zwiększenie zawartości sodu. Wyniki wyraźnie wskazują, że najmniej sodu dostarczał makaron gotowany w niesolonej wodzie. Jest to szczególnie ważne, ponieważ spożycie sodu w postaci soli kuchennej w diecie Polaków jest nadmierne (Pyka i in. 2019), a każda metoda zmniejszenia jego spożycia jest istotna. W grupie dzieci i młodzieży również zauważa się nadmierne spożycie soli (Núñez-Rivas i in. 2020; Wójcik i Kozioł-Kozakowska, 2021; Cheng i in. 2022). Już w 2007 roku WHO zaleciła, aby dzienne spożycie sodu dla osób dorosłych nie przekraczało 2000 mg, co odpowiada ilości zawartej w 5 g soli kuchennej. Dla dzieci i młodzieży zalecane maksymalne spożycie sodu powinno zostać zmniejszone w oparciu o zapotrzebowanie energetyczne tych grup wiekowych w stosunku do zapotrzebowania osób dorosłych (WHO, 2007; WHO, 2023a,b).

W Polsce spożywa się dwukrotnie więcej soli niż zalecana norma, głównie w postaci soli kuchennej dodawanej do posiłków (Rychlik i in. 2024). Tendencja do spożywania nadmiernych ilości soli rozwija się we wczesnym okresie życia, kiedy dorośli – kierując się własnymi upodobaniami smakowymi – używają nadmiernych ilości soli podczas przygotowywania posiłków dla dzieci (Koyama i Yoshiike, 2019; Masztalerz-Kozubek i in.

2020). Pobranie sodu można zmniejszyć między innymi poprzez zmianę sposobu przyrządzania potraw, tj. dodawanie soli po ugotowaniu, a nie podczas gotowania produktu. Badania przeprowadzone w Peru wykazały, że aż 84% osób przygotowujących posiłki w domu było skłonnych ograniczyć stosowanie soli podczas gotowania (Ponce-Lucero i in. 2020).

Podsumowując, wyniki przedstawione w publikacji **P2** pokazują, że najskuteczniejszym sposobem ograniczenia spożycia sodu jest nie dodawanie soli kuchennej do wody, w której gotuje się makaron, nawet jeśli producent zaleca dodanie soli do wody. Zaleca się doprawiać wyłącznie dodatki do makaronu, takie jak sosy, przy czym należy ograniczyć ilość soli podczas doprawiania, a zamiast niej używać ziół i naturalnych przypraw dla wzbogacenia smaku. Ponieważ sód w postaci soli kuchennej jest bardzo dobrze rozpuszczalny w wodzie i łatwo się rozprzestrzenia, zalecenie, aby nie dodawać soli do wody podczas gotowania, może mieć również zastosowanie do innych produktów spożywczych, takich jak kasze, ryż, warzywa i fasola, których podaż w wariantach posolonych może wpływać na wzrost pokrycia dziennego AI na sód. Z kolei płukanie makaronu po ugotowaniu prowadzi do zmniejszenia zawartości sodu w produkcie, jednak zabieg ten nie przywraca zawartości sodu porównywalnej z wariantem makaronu gotowanym bez soli. **Praca ta jest istotna, ponieważ dostarcza praktycznych, opartych na wynikach badań empirycznych wskazówek dotyczących prostych modyfikacji obróbki kulinarnej, które mogą realnie i bezkosztowo ograniczać pobranie sodu z dietą, a tym samym wspierać prewencję chorób cywilizacyjnych związanych z jego nadmiernym spożyciem.**

Praca ta dała podstawy do dalszych badań o charakterze fizjologiczno-metabolicznym.

## 4.3. Ocena wpływu metody gotowania makaronu (w wodzie niesolonej lub osolonej) na wchłanianie sodu – symulacja trawienia *in vitro*

Niewiele jest danych dotyczących wchłaniania sodu z makaronów i innych produktów spożywczych w przewodzie pokarmowym. Doświadczenia w tym obszarze mogą pomóc w lepszym zrozumieniu związku między zawartością soli w produktach spożywczych a wchłanianiem sodu, co może przyczynić się do opracowania strategii mających na celu ograniczenie spożycia soli kuchennej. Założono, że im wyższa zawartość sodu w ugotowanym makaronie, tym wyższy procent wchłaniania sodu z makaronu w przewodzie pokarmowym. Celem pracy badawczej **P3**, pt. *„The effect of pasta cooking method (unsalted versus salted water) on sodium absorption: an in vitro digestion study"*, była symulacja trawienia pięciu rodzajów makaronu fusilli (każdy o innym składzie) przy użyciu zaawansowanego modelu żołądkowo-jelitowego *in vitro*, w celu sprawdzenia, czy metoda gotowania (z solą lub bez) i skład makaronu mogą wpływać na wchłanianie sodu podczas trawienia.

### 4.3.1. Porównanie stopnia wchłaniania sodu z makaronu gotowanego w wodzie niesolonej i osolonej w zależności od odcinka symulowanego przewodu pokarmowego *in vitro*

Istotnie najwyższy stopień wchłaniania sodu zaobserwowano w dystalnym odcinku jelita cienkiego, niezależnie od rodzaju makaronu lub metody gotowania (z solą lub bez) (Tabela 4). Wchłanianie sodu wahało się od 46,2% sodu (makaron z wodorostami, gotowany z solą) do 67,7% sodu (makaron z wodorostami, gotowany bez soli) (Tabela 4). W żołądku i dystalnej części jelita cienkiego stopień wchłanianie sodu był wyższy w makaronie gotowanym bez soli (16,2% vs 13,3% i 67,7% vs 46,2%), podczas gdy w początkowych i środkowych częściach jelita cienkiego stopień wchłaniania sodu był wyższy w przypadku makaronu gotowanego z solą (20,0% vs 9,31% i 20,5% vs 6,81%).

**Tabela 4.** Porównanie wchłaniania sodu z makaronu gotowanego w wodzie niesolonej i osolonej w zależności od odcinka symulowanego przewodu pokarmowego *in vitro*, %

| | **Makaron z algami morskimi** | | | **Makaron 4-jajeczny** | | | **Makaron ryżowy** | | | **Makaron z pszenicy durum** | | | **Makaron pełnoziarnisty pszenno-żytni** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** |
| Żołądek | 16.2 $^{bC}$ ±1.02 | 13.3 $^{aA}$ ±0.65 | 0.033 | 16.2 $^{bB}$ ±0.76 | 13.6 $^{aA}$ ±0.47 | 0.021 | 16.3 $^{B}$ ±0.73 | 15.9 $^{B}$ ±0.44 | 0.061 | 12.4 $^{aB}$ ±0.53 | 17.5 $^{bB}$ ±0.44 | 0.019 | 6.57 $^{aA}$ ±0.09 | 12.5 $^{bA}$ ±0.31 | 0.013 |
| Początkowy odcinek jelita cienkiego | 9.31 $^{aB}$ ±0.44 | 20.0 $^{bB}$ ±1.02 | 0.002 | 12.8 $^{A}$ ±0.33 | 13.4 $^{A}$ ±0.28 | 0.059 | 13.9 $^{A}$ ±0.78 | 13.4 $^{A}$ ±0.41 | 0.065 | 8.81 $^{aA}$ ±0.23 | 13.4 $^{bA}$ ±0.39 | 0.020 | 10.1 $^{aB}$ ±0.30 | 19.0 $^{bC}$ ±0.17 | 0.009 |
| Środkowy odcinek jelita cienkiego | 6.81 $^{aA}$ ±0.51 | 20.5 $^{bB}$ ±0.79 | 0.008 | 17.6 $^{B}$ ±0.20 | 18.3 $^{B}$ ±0.73 | 0.060 | 20.7 $^{aC}$ ±0.29 | 23.0 $^{bC}$ ±0.48 | 0.041 | 13.7 $^{aB}$ ±0.19 | 14.8 $^{bA}$ ±0.56 | 0.048 | 21.4 $^{bC}$ ±0.11 | 15.2 $^{aB}$ ±0.22 | 0.023 |
| Końcowy odcinek jelita cienkiego | 67.7 $^{bD}$ ±2.23 | 46.2 $^{aC}$ ±2.04 | 0.021 | 53.4 $^{C}$ ±1.01 | 54.7 $^{C}$ ±0.99 | 0.058 | 49.1 $^{D}$ ±1.01 | 47.7 $^{D}$ ±0.72 | 0.052 | 65.0 $^{bC}$ ±0.84 | 54.3 $^{aC}$ ±0.22 | 0.037 | 61.9 $^{bD}$ ±0.92 | 53.3 $^{aD}$ ±0.15 | 0.036 |
| p value | 0.021 | 0.035 | | 0.039 | 0.018 | | 0.033 | 0.020 | | 0.041 | 0.030 | | 0.009 | 0.012 | |

$^{a, b}$ – średnie z różnymi indeksami górnymi w wierszach różnią się przy p<0,05 według testu HSD Tukeya, $^{A, B, C, D}$ – średnie z różnymi indeksami górnymi w kolumnach różnią się przy p<0,05 według testu HSD Tukeya; wartości przedstawiono jako średnia ± SD

W przypadku makaronu 4-jajecznego statystycznie istotne różnice w absorpcji sodu zaobserwowano tylko podczas trawienia w żołądku, przy czym wyższą absorpcję odnotowano w przypadku makaronu gotowanego bez soli w porównaniu z makaronem gotowanym z solą (16,2% vs 13,6%). Nie zaobserwowano istotnych różnic we wchłanianiu sodu pomiędzy makaronem 4-jajecznym gotowanym z solą i bez soli podczas trawienia w kolejnych odcinkach jelita cienkiego.

Statystycznie istotne różnice we wchłanianiu sodu z makaronu ryżowego gotowanego w wodzie, z solą lub bez, zaobserwowano jedynie w środkowym odcinku jelita cienkiego (20,7% vs 23,0%). Nie zaobserwowano istotnych różnic we wchłanianiu sodu z makaronu ryżowego gotowanego z solą lub bez podczas trawienia w żołądku ani w początkowym lub końcowym odcinku jelita cienkiego.

W przypadku makaronu z pszenicy durum zaobserwowano istotne różnice między produktami gotowanymi w wodzie niesolonej i osolonej na każdym etapie trawienia. W fazie żołądkowej, a także w początkowym i środkowym odcinku jelita cienkiego, wchłanianie sodu była wyższa dla makaronu z pszenicy durum gotowanego w wodzie osolonej w porównaniu z makaronem gotowanym w wodzie niesolonej, wynosząc odpowiednio 17,5% vs 12,4%, 13,4% vs 8,81% i 14,8% vs 13,7%. Natomiast wchłanianie sodu w dystalnej części jelita cienkiego była istotnie wyższa w makaronie z pszenicy durum gotowanym w niesolonej wodzie (65,0% vs 54,3%).

W przypadku makaronu pszenno-żytniego pełnoziarnistego zaobserwowano istotne różnice między produktami gotowanymi w niesolonej i osolonej wodzie w każdej fazie trawienia. W fazie żołądkowej, jak i w początkowej części jelita cienkiego, stopień wchłaniania sodu był wyższy w przypadku makaronu pszenno-żytniego pełnoziarnistego gotowanego w osolonej wodzie w porównaniu do makaronu gotowanego w niesolonej wodzie, z wartościami odpowiednio 12,5% vs 6,57% i 19,0% vs 10,1%. Natomiast wchłanianie sodu było znacząco wyższe w przypadku makaronu gotowanego w nieosolonej wodzie w środkowym i dystalnym odcinku jelita cienkiego i wynosiła odpowiednio 21,4% vs 15,2% i 61,9% vs 53,3%.

Zaobserwowano większą absorpcję sodu z makaronu gotowanego z solą w fazie trawienia żołądkowego (makaron z pszenicy durum i pełnoziarnisty makaron pszenno-żytni), początkowej fazie jelita cienkiego (makaron z wodorostami, makaron z pszenicy durum i pełnoziarnisty makaron pszenno-żytni) oraz środkowej fazie jelita cienkiego (makaron z wodorostami, makaron z pszenicy durum i makaron ryżowy). W końcowej fazie jelita cienkiego większą absorpcję sodu zaobserwowano w makaronie gotowanym bez soli (makaron z wodorostami, makaron z pszenicy durum i pełnoziarnisty makaron pszenno-żytni). Wyniki te sugerują, że dodatek soli podczas gotowania makaronu i fazy trawienia pokarmu wpływa na absorpcję sodu. W przypadku produktów roślinnych, w tym zbożowych, warto wspomnieć o błonniku pokarmowym, który obniża biodostępność składników mineralnych (Adams i in. 2018). Chociaż literatura na temat wpływu błonnika pokarmowego na biodostępność sodu jest ograniczona, co utrudnia jednoznaczną ocenę przyswajalności (Lakey-Beitia i in. 2021), badanie własne wykazało, że istotnie mniej sodu zostało przyswojone z makaronu pszenno-żytniego pełnoziarnistego (więcej błonnika) niż z makaronu ryżowego lub semoliny (mniej błonnika). Jednak zależność tą zaobserwowano tylko wtedy, gdy makaron był gotowany w niesolonej wodzie. Prawdopodobnym czynnikiem wpływającym na ten fakt jest to, że w makaronie pszenno-żytnim pełnoziarnistym gotowanym w osolonej wodzie, zawartość sodu wzrosła o około 30% w porównaniu do makaronu gotowanego w nieosolonej wodzie. Bianchi i in. (2019) postawili hipotezę, że sód jest wchłaniany w mniejszym stopniu z makaronów pełnoziarnistych niż z tych wykonanych z semoliny, jednak nie zostało to poparte wynikami. Wchłanianie składników mineralnych jest również ograniczone przez związki fenolowe, naturalne metabolity roślinne (Lakey-Beitia i in. 2021). W naszym badaniu wchłanianie sodu była najniższa dla makaronu z wodorostami w porównaniu z innymi rodzajami makaronu, ale tylko po ugotowaniu w niesolonej wodzie. Po ugotowaniu w osolonej wodzie stopień wchłanianie sodu z tego makaronu wzrósł o prawie 37% w porównaniu z wariantem niesolonym, osiągając około 98%. W tym przypadku makaron gotowany w osolonej wodzie zawierał o 12% więcej sodu niż makaron gotowany w niesolonej wodzie. Sól pochodząca z wodorostów morskich charakteryzują się niższą zawartością sodu w porównaniu do soli kuchennej, choć nie obserwuje się znacznej różnicy w odczuciu smaku słonego (Notowidjojo i in. 2021; Rakhasiya i in. 2025).

W przypadku większości (8 z 14 statystycznie istotnych wyników) makaronu gotowanego z solą, biorąc pod uwagę różne fazy symulowanego przewodu pokarmowego, zaobserwowano istotnie wyższe wartości procentowe absorpcji sodu w porównaniu z makaronem gotowanym bez soli. Sugeruje to, że w większości przypadków dodanie soli do gotującego się makaronu zwiększa absorpcję sodu z przewodu pokarmowego. Nadmierne wchłanianie sodu może prowadzić do negatywnych konsekwencji zdrowotnych, takich jak większe ryzyko chorób układu krążenia, nadciśnienia, udaru mózgu, nieprawidłowego rozwoju układu kostnego oraz pośredniego wpływu na częstość występowania otyłości i raka żołądka (Mazzuca i in. 2024; Pashaei i in. 2022; Rysová i Smídová, 2021).

### 4.3.2. Wchłanianie sodu z makaronu gotowanego z solą lub bez soli w zależności od składu makaronu oraz współczynnik korelacji Pearsona między zawartością sodu w ugotowanym makaronie a jego szybkością wchłaniania *in vitro*

Biorąc pod uwagę wartości ilościowe, statystycznie istotnie wyższą absorpcję sodu potwierdzono w przypadku makaronu gotowanego w osolonej wodzie w porównaniu z makaronem gotowanym w nieosolonej wodzie dla trzech rodzajów makaronu: makaronu z wodorostami (130,5 vs. 73,68 mg $kg^{-1}$), makaronu 4-jajecznego (82,47 vs. 72,58 mg $kg^{-1}$) i makaronu z pszenicy durum (120,4 vs. 80,83 mg $kg^{-1}$). Jednakże, biorąc pod uwagę wartości procentowe, statystycznie istotne różnice w absorpcji sodu potwierdzono między makaronem gotowanym w osolonej i nieosolonej wodzie dla trzech rodzajów makaronu: makaronu z wodorostami (97,8% vs. 61,8%), makaronu z pszenicy durum (90,46 vs. 82,85%) i makaronu pszenno-żytniego pełnoziarnistego (96,33 vs. 74,07%). Dodatkowo, stwierdzono silną dodatnią korelację ($r = 0{,}871$) pomiędzy zawartością sodu w ugotowanym makaronie a szybkością jego wchłaniania w przewodzie pokarmowym (Tabela 5). W badaniu opublikowanym przez Passannanti i in. (2017) przy użyciu dynamicznego modelu trawienia *in vitro* (Tiny-TIM) wykazano, że czynniki takie jak matryca pokarmowa (rodzaj zboża) i warunki fizykochemiczne (pH, czas przebywania w poszczególnych częściach przewodu pokarmowego) znacząco wpływają na ilość sodu dostępnego do wchłaniania. Wyniki podkreślają przydatność modeli *in vitro* w badaniu wchłaniania składników pokarmowych bez konieczności wykonywania badań z udziałem ludzi.

**Tabela 5.** Wchłanianie sodu (Na) z makaronu gotowanego z solą lub bez soli w zależności od składu makaronu oraz współczynnik korelacji Pearsona między zawartością Na w ugotowanym makaronie a jego szybkością wchłaniania *in vitro*

| | **Makaron z algami morskimi** | | | **Makaron 4-jajeczny** | | | **Makaron ryżowy** | | | **Makaron z pszenicy durum** | | | **Makaron pełnoziarnisty pszenno-żytni** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** | **Niesolony** | **Solony** | **p value** |
| Zawartość Na w ugotowanym makaronie, mg $kg^{-1}$ | 119.2 [a] ±6.02 | 133.4 [b] ±8.14 | 0.032 | 76.60 ±2.51 | 82.70 ±3.05 | 0.057 | 142.2 [b] ±6.38 | 126.5 [a] ±5.60 | 0.031 | 97.56 [a] ±3.55 | 133.1 [b] ±1.87 | 0.022 | 140.7 [b] ±3.18 | 109.6 [a] ±4.08 | 0.008 |
| Zaabsorbowana zawartość Na, mg $kg^{-1}$ | 73.68 [a] ±3.15 | 130.5 [b] ±4.52 | 0.026 | 72.58 [a] ±3.75 | 82.47 [b] ±1.82 | 0.045 | 130.5 ±7.02 | 126.5 ±1.58 | 0.059 | 80.83 [a] ±5.57 | 120.4 [b] ±3.03 | 0.009 | 104.2 ±2.31 | 105.6 ±4.02 | 0.071 |
| % absorpcji Na * | 61.80 [a] ±3.04 | 97.79 [b] ±3.22 | 0.030 | 94.75 ±4.17 | 99.72 ±2.58 | 0.061 | 91.76 ±3.45 | 99.96 ±4.09 | 0.064 | 82.85 [a] ±1.77 | 90.46 [b] ±5.12 | 0.047 | 74.07 [a] ±4.06 | 96.33 [b] ±1.25 | 0.020 |
| r | 0.871 | | | | | | | | | | | | | | |

* Zawartość Na w ugotowanym makaronie przyjęto jako 100%; r – współczynnik korelacji Pearsona; [a, b] – średnie z różnymi indeksami górnymi w wierszach różnią się przy $p<0,05$ według testu HSD Tukeya; wartości przedstawiono jako średnia ± SD

Podsumowując, wyniki uzyskane w publikacji **P3** pokazują, że gotowanie w osolonej wodzie ma znaczący wpływ na zwiększenie wchłaniania sodu w symulowanym przewodzie pokarmowym *in vitro,* a procent wchłaniania sodu z makaronu jest dodatnio skorelowany z zawartością sodu w produkcie, która z kolei zależy od stężenia soli w wodzie do gotowania. Statystycznie istotnie wyższy procent wchłaniania sodu potwierdzono dla makaronu gotowanego w osolonej wodzie w porównaniu z makaronem gotowanym w nieosolonej wodzie dla trzech z pięciu analizowanych makaronów: makaronu z wodorostami, makaronu z pszenicy durum i makaronu pszenno-żytniego pełnoziarnistego. Sugeruje to, że skład recepturowy makaronu jest prawdopodobnie najważniejszy, ponieważ był czynnikiem różnicującym. **Przeprowadzone badania są istotne, ponieważ w sposób ilościowy i oparty na symulacji trawienia *in vitro* wykazują, że sposób przygotowania makaronu – a nie wyłącznie jego deklarowany skład – ma kluczowe znaczenie dla rzeczywistego wchłaniania sodu w przewodzie pokarmowym, dostarczając naukowych podstaw do formułowania praktycznych zaleceń żywieniowych ukierunkowanych na redukcję spożycia soli w populacji.** Ze względu na zbyt duże ilości spożywanej soli w całej populacji, konieczne są różnorodne formy edukacji żywieniowej, uwzględniające temat wchłaniania sodu z przewodu pokarmowego.

## 4.4. Analiza zawartości sodu w chlebie, porównanie spożycia zalecanych dziennych porcji chleba względem norm wystarczającego spożycia sodu w diecie dzieci oraz oszacowanie udziału chleba w całkowitym spożyciu soli w diecie dzieci w wieku 1–12 lat

Chleb jest powszechnym składnikiem diety ludzi na całym świecie, większość populacji konsumuje go kilka razy dziennie (Laskowski i in. 2019). Ze względu na swoją powszechność, ma znaczący udział w dziennym spożyciu soli (Pashaei i in. 2022; Carcea, 2020). Sól jest ważnym dodatkiem technologicznym, który poprawia jakość pieczywa (Rysová i Šmídová, 2021; Allison i Fouladkhah, 2018), jednak jej nadmierne spożycie w okresie dzieciństwa może zwiększać ryzyko nadciśnienia tętniczego, wpływać negatywnie na rozwój kości, sprzyjać wystąpieniu otyłości i nadmiernie obciążać nerki (Rychlik i in. 2024; Szajewska i in. 2021; Mazzuca i in. 2024). Redukcja soli w chlebie jest możliwa i z reguły akceptowalna przez konsumentów (Lobo i Ferreira, 2021; Jaenke i in. 2017; McMahon i in. 2017), ale powinna być stopniowa (Dybkowska i in. 2015), a sama sól zastąpiona odpowiednimi zamiennikami (WHO, 2024; Gorman i in. 2023; Barnett i in. 2018). Celem pracy badawczej **P4** pt. *„Bread consumed in recommended portions does not provide excessive amounts of sodium and salt in children's diet"* była analiza zawartości sodu w wybranych rodzajach chleba, porównanie pobrania sodu z zalecanych dziennych porcji chleba względem norm wystarczającego spożycia sodu w diecie dzieci oraz oszacowanie udziału chleba i innych wybranych produktów zbożowych w dziennym rekomendowanym spożyciu soli dla różnych grup wiekowych dzieci w wieku 1–12 lat.

### 4.4.1. Zawartość sodu w chlebie

W pracy przedstawiono średnią zawartość sodu i soli w chlebie, wyrażoną na 1000 g i na kromkę chleba (średnio 30 g). Średnio chleb zawierał 7258,6 ± 891 mg sodu/1000 g i 217,8 ± 26,7 mg sodu/30 g. Analizy wykazały najwyższą zawartość sodu i soli w chlebie żytnim (średnio 8333 mg sodu/1000 g i 20 833 mg soli/1000 g; 250 mg sodu/30 g i 625 mg soli/30 g), a najniższą w chlebie orkiszowym (średnio 6066 mg sodu/1000 g i 15 165 mg soli/1000 g; 182 mg sodu/30 g i 455 mg soli/30 g). Statystycznie istotne różnice ($p<0,0001$) w zawartości sodu i soli w różnych rodzajach chleba przedstawiono w Tabeli 6. Różnice między wartościami sodu i soli na 1000 g i na 30 g są takie same, ponieważ ekwiwalent soli = Na × 2,5. Dodatkowo wykonywane analizy zawartości sodu w różnych rodzajach mąk wykazały, że mąka nie jest znaczącym źródłem sodu w chlebie. Wysoka zawartość sodu w chlebie wynika z soli dodawanej do chleba na etapie produkcji. Autorzy innych badań deklarowali niższe niż uzyskane w badaniu własnym wartości sodu w chlebie pszennym: 3482 ± 135 mg/1000 g (Martins i in. 2017), 159 ± 0,2 mg/1000 g (Odunlade i in. 2017), 4191 ± 588 mg/1000 g (Jessen i in. 2020); chlebie żytnim: 260 ± 10 mg/1000 g (Carocho i in. 2020), 3898 ± 1212 mg/1000 g (Jessen i in. 2020) i 7906 ± 72–8153 ± 484 mg/1000 g oraz w chlebie graham: 6369 ± 180–6509 ± 19 mg/1000 g, ale wyższe w chlebie orkiszowym: 6378 ± 149–6598 ± 47 mg/1000 g (Litwinek i in. 2018). W badaniach własnych stwierdzono, że chleb żytni charakteryzował się najwyższą zawartością soli spośród wszystkich rodzajów chleba. W badaniu Bazarnik i Dybkowskiej (2015) najwyższą zawartość soli stwierdzono w bagietkach pszennych (3,01%), a najniższą w cieście francuskim (0,93%). Zawartość soli w białym pieczywie tostowym różnych producentów była podobna i wynosiła średnio 1,33%. Porównując tę wartość z analizą przeprowadzoną w badaniu własnym, pszenny chleb tostowy zawierał mniej soli (około 0,6%). Różnice między wynikami badań własnych, a wynikami innych autorów mogą wynikać z przepisów krajowych (limity dodawanej soli w produktach piekarniczych), dodatków do żywności oraz odmiennych receptur pieczywa stosowanych w piekarniach w Polsce i innych regionach świata. Skład gleby, stosowanie nawozów oraz czynniki geograficzne mogą również wpływać na zawartość składników mineralnych, w tym sodu, w ziarnach (Carocho i in. 2020; Torrinha i in. 2019).

**Tabela 6.** Średnia zawartość sodu (Na) i soli w mg na 1000 g i na 30 g (1 kromkę) świeżego produktu w wybranych chlebach

| Rodzaj chleba | | mg / 1000 g | | mg / 30 g | |
|---|---|---|---|---|---|
| | n | Na | sól | Na | sól |
| Chleb pszenny | 10 | 7598 $^{ac}$ | 18995 $^{ac}$ | 228 $^{ac}$ | 570 $^{ac}$ |
| Chleb żytni | 10 | 8333 $^{a}$ | 208325 $^{a}$ | 250 $^{a}$ | 625 $^{a}$ |
| Chleb pszenno-żytni | 10 | 8099 $^{ab}$ | 20247 $^{ab}$ | 243 $^{ab}$ | 607,5 $^{ab}$ |
| Chleb tostowy pszenny | 10 | 6116 $^{d}$ | 15290 $^{d}$ | 183,5 $^{d}$ | 458,8 $^{d}$ |
| Chleb tostowy pełnoziarnisty | 10 | 7465 $^{bc}$ | 18662 $^{bc}$ | 224 $^{bc}$ | 560 $^{bc}$ |
| Chleb graham | 10 | 7133 $^{c}$ | 17832 $^{c}$ | 214 $^{c}$ | 535 $^{c}$ |
| Chleb orkiszowy | 10 | 6066 $^{d}$ | 15165 $^{d}$ | 182 $^{d}$ | 455 $^{d}$ |
| Wartość średnia | 70 | 7258,6 | 18146,2 | 217,8 | 544,5 |
| SD | | 891 | 2227 | 26,7 | 66,8 |
| SEM | | 336,8 | 841,7 | 10,1 | 25,2 |

Wyniki przedstawiono jako średnie z 2 powtórzeń; sól = Na × 2,5. SD – odchylenie standardowe; SEM – błąd standardowy średnich; $^{a, b, c, d}$ – średnie z różnymi indeksami górnymi w kolumnach różnią się przy p<0,0001 w teście HSD Tukeya.

### 4.4.2. Chleb jako źródło sodu

Aby określić dzienne pobranie sodu z porcją chleba, odwołano się do zaleceń dotyczących średnich wartości spożycia chleba dla różnych grup wiekowych dzieci: 1–3 lat: 20 g; 4–6 lat: 32,5 g; 7–9 lat: 45 g; 10–12 lat: 80 g (Weker i Barańska, 2014; Weker, 2015). Dzienne spożycie zalecanej porcji chleba we wszystkich grupach wiekowych nie przekraczało wystarczającego spożycia sodu (Tabela 7). Niezależnie od grupy wiekowej, najpopularniejszymi źródłami sodu i soli były: chleb żytni > chleb pszenno-żytni > chleb pszenny > chleb tostowy pełnoziarnisty > chleb graham > chleb tostowy pszenny > chleb orkiszowy. Średnie spożycie sodu z porcją chleba było następujące: 10–12 lat (44,6% AI) > 7–9 lat (27,2% AI) > 4–6 lat (19,7% AI) > 1–3 lata (16,2% AI). W badaniach nad nawykami żywieniowymi dzieci chleb często pojawia się jako jeden z najczęściej spożywanych produktów, co może znacząco przyczynić się do nadmiernego spożycia soli (Rosi i in. 2019; Quader i in. 2017). W większości przypadków spożycie soli w populacji dzieci przekracza zalecane poziomy (Quader i in. 2017; Bricarello i in. 2021; Campanozzi i in. 2015). Głównym źródłem soli w ich diecie jest żywność, do której sól jest dodawana na etapie produkcji (Núñez-Rivas i in. 2020). Spośród nich chleb jest głównym źródłem soli, zarówno ze względu na zawartość soli w 100 g produktu, jak i wielkość spożywanej porcji (Rosi i in. 2019; Winiarska-Mieczan i in. 2019a). Oprócz pieczywa i produktów zbożowych, inne źródła soli obejmują przetworzone produkty mięsne (takie jak wędliny, kiełbasy, parówki i konserwy mięsne), produkty mleczne (głównie sery podpuszczkowe i serki do kanapek) oraz warzywa w puszkach, które często spożywa się z pieczywem (Kunachowicz i in. 2020). Oznacza to, że jeden posiłek może jednocześnie dostarczyć znacznych ilości soli z różnych źródeł.

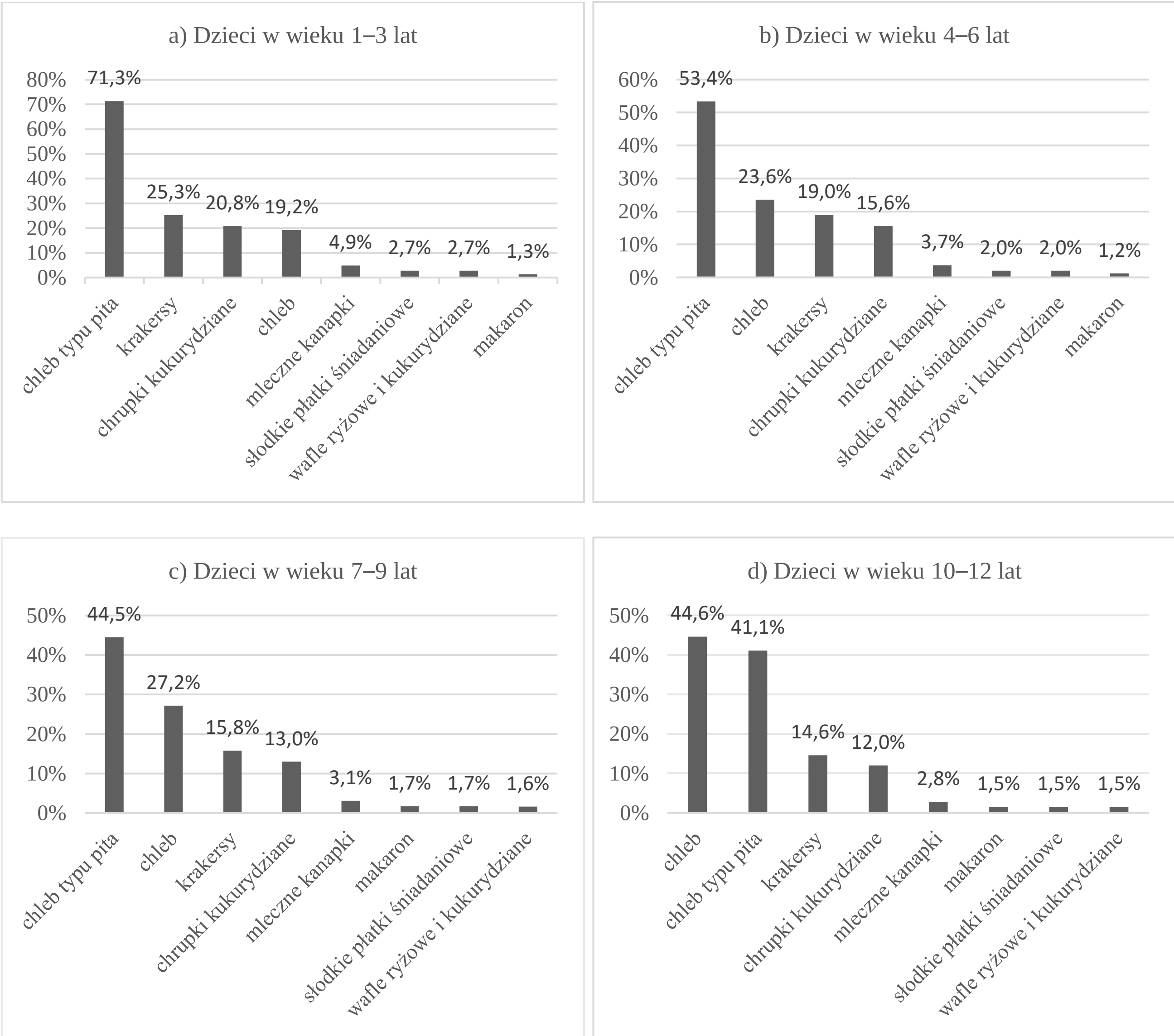
**Tabela 7.** Pobranie sodu (Na) w mg ze średnią zalecaną dzienną porcją chleba oraz stosunek spożycia Na ze średnią zalecaną dzienną porcją chleba do dziennego spożycia Na (%)

| **Pobranie sodu (mg) z zalecaną dzienną porcją chleba** | | | | | **Stosunek pobrania sodu z zalecaną dzienną porcją chleba do dziennego AI sodu (%)** | | | |
|---|---|---|---|---|---|---|---|---|
| **Grupa wiekowa** | **1–3** | **4–6** | **7–9** | **10–12** | **1–3** | **4–6** | **7–9** | **10–12** |
| Porcja chleba (g) / dzień | 20 | 32,5 | 45 | 80 | | | | |
| AI sodu (mg) | | | | | 750 | 1000 | 1200 | 1300 |
| Chleb pszenny | 151,9 [ac] | 246,8 [ac] | 341,8 [ac] | 607,6 [ac] | 20,3 [ac] | 24,7 [ac] | 28,5 [ac] | 46,7 [ac] |
| Chleb żytni | 166,6 [a] | 270,8 [a] | 374,9 [a] | 666,6 [a] | 22,2 [a] | 27,1 [a] | 31,2 [a] | 51,3 [a] |
| Chleb pszenno-żytni | 161,9 [ab] | 263,2 [ab] | 364,4 [ab] | 647,8 [ab] | 21,6 [ab] | 26,3 [ab] | 30,4 [ab] | 49,8 [ab] |
| Chleb tostowy pszenny | 122,3 [d] | 198,7 [d] | 275,1 [d] | 489,0 [d] | 16,3 [d] | 19,9 [d] | 23,0 [d] | 37,6 [d] |
| Chleb tostowy pełnoziarnisty | 149,3 [bc] | 242,5 [bc] | 335,8 [bc] | 597,0 [bc] | 19,9 [bc] | 24,3 [bc] | 28,0 [bc] | 45,9 [bc] |
| Chleb graham | 142,6 [c] | 231,8 [c] | 320,9 [c] | 570,5 [c] | 19,0 [c] | 23,2 [c] | 26,7 [c] | 43,9 [c] |
| Chleb orkiszowy | 121,2 [d] | 197,0 [d] | 272,8 [d] | 485,0 [d] | 16,2 [d] | 19,7 [d] | 22,7 [d] | 37,3 [d] |
| Średnia | 145,1 | 235,8 | 326,5 | 580,5 | 19,2 | 23,6 | 27,2 | 44,6 |

[a, b, c, d] – średnie z różnymi indeksami górnymi w kolumnach różnią się przy $p<0{,}0001$ w teście HSD Tukeya; zalecana dzienna porcja chleba dla dzieci w wieku 1–3 lat pochodziła z publikacji Weker i Barańskiej (2014), a dla dzieci w wieku 4–6, 7–9 i 10–12 lat pochodziła z publikacji Weker (2015).

### 4.4.3. Udział chleba i innych produktów zbożowych w całkowitym spożyciu soli w diecie dzieci

Na podstawie własnych wyników oraz dostępnych w literaturze informacji dotyczących zawartości soli w produktach zbożowych, oszacowano ich udział w spożyciu soli w diecie dzieci. Wykres 2 przedstawia udział produktów zbożowych w dziennym zalecanym spożyciu soli dla dzieci w różnych grupach wiekowych. W każdej grupie wiekowej najwyższe wartości odnotowano dla chleba (19,2–44,6% dziennego zalecanego pobrania soli) i chlebów pita (41,1–71,3%) – rodzaju chleba wypiekanego z mąki, spożywanego z różnymi dodatkami, popularnego w kuchniach europejskich i bliskowschodnich. Produkty takie jak chrupki kukurydziane (12,0–20,8%) i krakersy (14,6–25,3%), powszechnie spożywane odpowiednio przez młodsze i starsze dzieci, również znacząco przyczyniają się do dziennego zalecanego spożycia soli we wszystkich grupach wiekowych. Natomiast makaron, ryż i wafle kukurydziane, spożywane zgodnie z ustaloną porcją, nie przyczyniają się znacząco do nadmiernego spożycia soli we wszystkich grupach wiekowych, ponieważ ich udział w dziennym zalecanym spożyciu soli był marginalny (1,2–2,7%). Wśród dzieci w wieku 1–3 i 4–6 lat w największym stopniu do pokrycia zalecanego dziennego spożycia soli przyczynia się chleb typu pita, a najmniej makaron; wśród dzieci w wieku 7–9 lat największym stopniu również chleb typu pita, a najmniej ryż i wafle kukurydziane; wśród dzieci w wieku 10–12 lat w największym stopniu chleb, a najmniej słodkie płatki śniadaniowe = ryż i wafle kukurydziane = makaron (Wykres 2).




**Wykres 2.** Udział wybranych produktów zbożowych w dziennym rekomendowanym spożyciu soli dla różnych grup wiekowych dzieci (%)

Wielkość porcji dla chleba ustalono na podstawie Weker i Barańskiej (2014) i Weker (2015); Wielkość porcji dla makaronu ustalono na podstawie Jachimowicz i in. (2021); Wielkość porcji dla mlecznych kanapek ustalono na podstawie Jachimowicz i in. (2023); Wielkość porcji dla płatków śniadaniowych ustalono na podstawie Winiarskiej-Mieczan i in. (2016) i uśredniono; Wielkość porcji dla chrupek kukurydzianych, krakersów, wafli ryżowych i kukurydzianych oraz chlebów typu pita ustalono na podstawie informacji zamieszczonych na etykietach produktów spożywczych i sugestii producentów

Zaobserwowano znaczną zmienność zarówno pomiędzy, jak i wewnątrz analizowanych produktów zbożowych. Produktami o najwyższej zawartości soli były chleb (wartości minimum–maksimum: 15,2–208,3 g/1000 g), krakersy (15,0–22,5 g/1000 g) i chleb typu pita (15,0–20,0 g/1000 g), natomiast makarony miały najniższą zawartość soli (0–0,5 g/1000 g). Zawartość soli w gramach na 1000 g produktów zbożowych można przedstawić jako: chleb > krakersy > chleb typu pita > chrupki kukurydziane > ryż i wafle kukurydziane > mleczne kanapki > słodkie płatki śniadaniowe > makaron. Oznacza to, że chleb, w porównaniu z innymi produktami zbożowymi, zawiera najwięcej soli na 1000 g (Tabela 8). Chleb, bułki i tortille dostarczały 7,7% sodu dziennie w diecie dzieci i młodzieży z populacji amerykańskiej (Papanikolaou i Fulgoni, 2017). Dzienne pobranie sodu z chleba wynosiło około 6%, a z płatków śniadaniowych około 7% w badaniu 10–12-letnich dzieci z populacji greckiej (Magriplis i in. 2011).

**Tabela 8.** Dane dotyczące zawartości soli (minimum – maksimum; g/1000 g) w chlebie i innych produktach zbożowych

| **Produkt** | **Zawartość soli (g/1000 g)** | **Źródło** |
|---|---|---|
| Chleb | 15.2 – 208.3 | Badanie własne |
| Makaron | 0 – 0.5 | Jachimowicz i in. 2021 |
| Mleczne kanapki | 0.08 – 4.8 | Jachimowicz i in. 2023 |
| Słodkie płatki śniadaniowe | 0.62 – 1.78 | Winiarska-Mieczan i in. 2016 |
| Chrupki kukurydziane | 13.1 ± 0.00 * | Kulczak i in. 2012 |
| Krakersy | 15.0 – 22.5 | Martini i in. 2022 |
| Wafle ryżowe i kukurydziane | 3.0 – 10.0 | Martini i in. 2022 |
| Chleb typu pita | 15.0 – 20.0 | Martini i in. 2022 |

* Nie podano informacji o wartościach minimalnych i maksymalnych.

Podsumowując, wyniki uzyskane w publikacji **P4** pokazują, że dzienne spożycie zalecanej porcji chleba we wszystkich grupach wiekowych dzieci nie przekraczało dziennego zalecanego spożycia soli, jednak gdy dzieci przekraczają dzienne zalecane spożycie chleba, może się to przyczyniać się do nadmiernej podaży sodu. Chleb orkiszowy charakteryzował się najniższą zawartością soli, natomiast chleb żytni najwyższą. Może to wynikać z faktu, że podczas produkcji chleba żytniego dopuszcza się wyższy dodatek soli. **Praca ta jest ważna, ponieważ dostarcza rzetelnych danych ilościowych na temat rzeczywistego udziału chleba w podaży sodu w diecie dzieci, wskazując zarówno na znaczenie kontroli wielkości porcji, jak i na potencjał modyfikacji receptur jako skutecznego narzędzia prewencji nadmiernego spożycia soli już na wczesnym etapie życia.** Inne produkty zbożowe, takie jak płatki śniadaniowe, makarony, słodkie i słone przekąski, popularne wśród dzieci, charakteryzowały się niższą zawartością sodu względem chleba, ale jedzone w nadmiernych ilościach, mogą przyczyniać się do przekroczenia ustalonych limitów soli.

## 4.5. Ocena zawartości sodu i obliczenie zawartości soli w wybranych słodkich produktach zbożowych oraz oszacowanie w jakim stopniu wybrane słodkie produkty zbożowe przyczyniają się do pobrania sodu i soli przez dzieci w wieku 1–14 lat

Słodkie produkty zbożowe są bardzo chętnie spożywane przez dzieci (Piasecka i Lesiów, 2019; Potvin Kent i in. 2017; Sanchez-Siles i in. 2022). Nie jest to powszechnie wiadome, że zawierają one znaczne ilości soli i sodu. Kluczowe jest uświadamianie społeczeństwa na temat najważniejszych źródeł soli i sodu w diecie dzieci, zwłaszcza tych, które nie są oczywiste. Kompleksowe zrozumienie tego zagadnienia jest niezbędne do wdrożenia skutecznych strategii mających na celu zmniejszenie ryzyka chorób niezakaźnych związanych ze stylem życia, w tym z nadmierną podażą sodu. Celem pracy badawczej **P5**, pt. *„Sweet-tasting cereal products as a source of sodium and salt in children's diets"*, była ocena zawartości sodu i obliczenie zawartości soli w słodkich produktach zbożowych, a także oszacowanie, w jakim stopniu produkty te przyczyniają się do spożycia sodu i soli przez dzieci w wieku 1–14 lat.

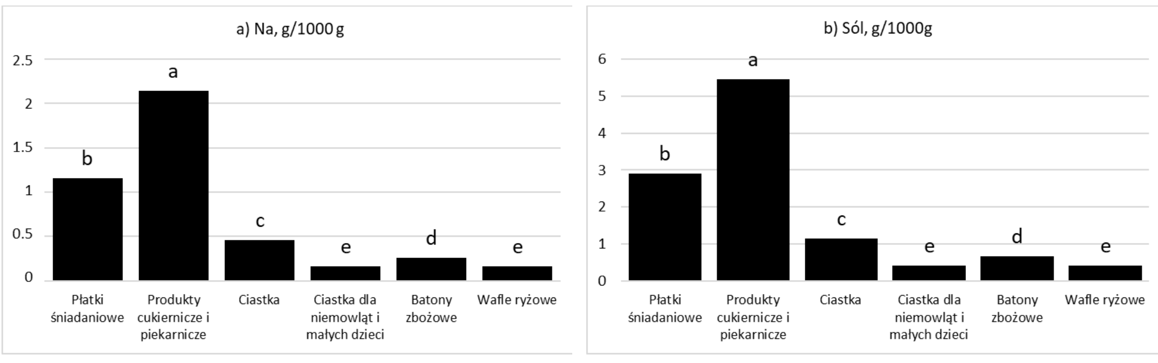
### 4.5.1. Zawartość sodu i soli w wybranych słodkich produktach zbożowych

Na podstawie składu recepturowego stwierdzono, że większość analizowanych słodkich produktów zbożowych zawierała dodatek soli – wszystkie wyroby cukiernicze i piekarnicze, kukurydziane płatki śniadaniowe, pełnoziarniste płatki śniadaniowe i muesli; większość ciastek, batonów muesli oraz wielozbożowych płatków śniadaniowych i owsianek. Natomiast sezamki, ciastka dla niemowląt i małych dzieci, a także większość wafli ryżowych oraz batonów zbożowych z nadzieniem nie zawierały dodatku soli (Tabela 9). Dodatek soli do słodkich produktów zbożowych przyczynił się do wzrostu zawartości sodu w tych produktach. Sól dodaje się do produktów słodkich w celu zrównoważenia smaków i wzmocnienia słodkiego smaku, zapobiegając nadmiernemu uczuciu mdłości (Vucurovic i in. 2017).

**Tabela 9.** Wykaz badanych produktów zbożowych o słodkim smaku

| Produkt | n | % produktów z dodatkiem soli |
|---|---|---|
| Płatki śniadaniowe | 38 | |
| Kukurydziane | 8 | 100 |
| Owsiane | 5 | 60 |
| Muesli | 11 | 100 |
| Pełnoziarniste | 4 | 100 |
| Otrębowe | 4 | 0 |
| Wielozbożowe | 6 | 67 |
| Wyroby cukiernicze i piekarnicze | 78 | |
| Drożdżowe bez dodatków | 15 | 100 |
| Drożdżowe z dodatkami | 25 | 100 |
| Wykonane z ciasta francuskiego | 38 | 100 |
| Ciastka | 31 | 87 |
| Ciastka dla niemowląt i małych dzieci | 10 | 0 |
| Batony zbożowe | 47 | |
| Muesli | 25 | 68 |
| Z nadzieniem | 12 | 17 |
| Sezamki | 10 | 0 |
| Wafle ryżowe | 10 | 10 |

Zawartość sodu i soli (na 1000 g) w analizowanych produktach wynosiła: wyroby cukiernicze i piekarnicze (2,145 ± 0,693 g sodu, 5,450 ± 1,761 g soli) > płatki śniadaniowe (1,159 ± 1,107 g sodu, 2,909 ± 2,844 g soli) > ciastka (0,460 ± 0,016 g sodu, 1,154 ± 0,040 g soli) > batony zbożowe (0,261 ± 0,188 g sodu, 0,656 ± 0,472 g soli) > ciastka dla niemowląt i małych dzieci (0,165 ± 0,019 g sodu, 0,413 ± 0,048 g soli) = wafle ryżowe (0,162 ± 0,026 g Na, 0,406 ± 0,074 g soli). Biorąc pod uwagę, że sól = sód × 2,54, korelacje między produktami są identyczne dla sodu i soli (Wykres 3, Tabela 10).




**Wykres 3.** Średnia zawartość sodu (Na) i soli w badanych produktach zbożowych o słodkim smaku; [a, b, c, d, e] – wartości z różnymi indeksami górnymi różnią się przy $p<0,05$ według testu Duncana

Stwierdzono, że słodkie produkty zbożowe zawierają znaczne ilości sodu i soli (0,162–2,145 g sodu na 1000 g; co odpowiada 0,406–5,45 g soli na 1000 g). W zależności od wielkości porcji i grupy wiekowej, pojedyncza porcja – szczególnie w przypadku wyrobów cukierniczych charakteryzujących się największym udziałem – może zawierać do 0,5 g soli. Herbatniki mleczne w badaniu Muneer i in. (2020) zawierały 0,215–0,37 g sodu na 100 g, a herbatniki bezglutenowe w badaniu Luque-Vilca i in. (2024) – 0,17–0,32 g soli na 100 g. Biorąc pod uwagę popularność słodkich przekąsek, ich częste spożycie przez dzieci oraz to, że są nieoczywistym źródłem sodu, produkty te mogą w znacznym stopniu przyczynić się do przekroczenia ustalonych norm dla sodu w diecie. Dlatego reformulacje składu słodkich produktów zbożowych są zalecane. Analizy sensoryczne przeprowadzone przez Ayed i in. (2021) wykazały, że obniżenie zawartości soli o 33% (z 1,05 g do 0,86 g soli na 100 g) w słodkich kruchych ciastkach pozytywnie wpłynęło na ich teksturę – uzyskano produkty bardziej chrupiące.

**Tabela 10.** Średnia zawartość sodu i soli w badanych produktach zbożowych o słodkim smaku

| | g/kg | | 1 porcja | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Na** | **Sól** | **Na** | | | | | **Sól** | | | | |
| **Grupa wiekowa** | | | **< 1** | **1 – 3** | **4 – 6** | **7 – 10** | **11 – 14** | **< 1** | **1 – 3** | **4 – 6** | **7 – 10** | **11 – 14** |
| Płatki śniadaniowe | | | | | | | | | | | | |
| Średnia | 1.159 | 2.909 | - | 0.035 | 0.035 | 0.035 | 0.035 | - | 0.087 | 0.087 | 0.087 | 0.087 |
| Minimalna wartość | 0.108 | 0.273 | - | 0.006 | 0.006 | 0.006 | 0.006 | - | 0.015 | 0.015 | 0.015 | 0.015 |
| Maksymalna wartość | 4.043 | 10.27 | - | 0.082 | 0.082 | 0.082 | 0.082 | - | 0.205 | 0.205 | 0.205 | 0.205 |
| SD | 1.107 | 2.844 | - | 0.023 | 0.023 | 0.023 | 0.023 | - | 0.059 | 0.059 | 0.059 | 0.059 |
| Analiza wariancji | 1.226 | 8.086 | - | 5.48E-04 | 5.48E-04 | 5.48E-04 | 5.48E-04 | - | 0.003 | 0.003 | 0.003 | 0.003 |
| Wyroby cukiernicze i piekarnicze | | | | | | | | | | | | |
| Średnia | 2.145 | 5.450 | - | 0.107 | 0.107 | 0.107 | 0.139 | - | 0.269 | 0.269 | 0.269 | 0.350 |
| Minimalna wartość | 1.002 | 2.546 | - | 0.049 | 0.049 | 0.049 | 0.064 | - | 0.123 | 0.123 | 0.123 | 0.160 |
| Maksymalna wartość | 2.786 | 7.076 | - | 0.151 | 0.151 | 0.151 | 0.196 | - | 0.378 | 0.378 | 0.378 | 0.492 |
| SD | 0.693 | 1.761 | - | 0.036 | 0.036 | 0.036 | 0.047 | - | 0.091 | 0.091 | 0.091 | 0.118 |
| Analiza wariancji | 0.481 | 3.100 | - | 0.001 | 0.001 | 0.001 | 0.002 | - | 0.008 | 0.008 | 0.008 | 0.014 |
| Ciastka | | | | | | | | | | | | |
| Średnia | 0.460 | 1.154 | - | - | 0.016 | 0.016 | 0.023 | - | - | 0.040 | 0.040 | 0.058 |
| Minimalna wartość | 0.418 | 1.049 | - | - | 0.012 | 0.012 | 0.017 | - | - | 0.030 | 0.030 | 0.043 |
| Maksymalna wartość | 0.467 | 1.172 | - | - | 0.022 | 0.022 | 0.031 | - | - | 0.054 | 0.054 | 0.077 |
| SD | 0.016 | 0.040 | - | - | 0.003 | 0.003 | 0.004 | - | - | 0.008 | 0.008 | 0.011 |
| Analiza wariancji | 0.0003 | 0.0016 | - | - | 9.34E-06 | 9.34E-06 | 1.91E-05 | - | - | 5.88E-05 | 5.88E-05 | 1.17E-04 |
| Ciastka dla niemowląt i małych dzieci | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Średnia | 0.165 | 0.413 | 1.48E-03 | 1.48E-03 | - | - | - | 3.72E-03 | 3.72E-03 | - | - | - |
| Minimalna wartość | 0.128 | 0.321 | 1.15E-03 | 1.15E-03 | - | - | - | 2.89E-03 | 2.89E-03 | - | - | - |
| Maksymalna wartość | 0.188 | 0.473 | 1.68E-03 | 1.68E-03 | - | - | - | 4.25E-03 | 4.25E-03 | - | - | - |
| SD | 0.019 | 0.048 | 1.54E-04 | 1.54E-04 | - | - | - | 3.86E-04 | 3.86E-04 | - | - | - |
| Analiza wariancji | 0.002 | 0.011 | 2.37E-08 | 2.37E-08 | - | - | - | 1.49E-07 | 1.49E-07 | - | - | - |
| Batony zbożowe | | | | | | | | | | | | |
| Średnia | 0.261 | 0.656 | - | 0.005 | 0.007 | 0.007 | 0.007 | - | 0.013 | 0.016 | 0.016 | 0.016 |
| Minimalna wartość | 0.078 | 0.195 | - | 0.002 | 0.002 | 0.002 | 0.002 | - | 0.004 | 0.005 | 0.005 | 0.005 |
| Maksymalna wartość | 0.511 | 1.283 | - | 0.010 | 0.013 | 0.013 | 0.013 | - | 0.026 | 0.032 | 0.032 | 0.032 |
| SD | 0.188 | 0.472 | - | 0.004 | 0.005 | 0.005 | 0.005 | - | 0.009 | 0.012 | 0.012 | 0.012 |
| Analiza wariancji | 0.035 | 0.223 | - | 1.42E-05 | 2.21E-05 | 2.21E-05 | 2.21E-05 | - | 8.92E-05 | 1.39E-04 | 1.39E-04 | 1.39E-04 |
| Wafle ryżowe | | | | | | | | | | | | |
| Średnia | 0.162 | 0.406 | - | 2.43E-03 | 2.43E-03 | 2.43E-03 | 2.43E-03 | - | 6.09E-03 | 6.09E-03 | 6.09E-03 | 6.09E-03 |
| Minimalna wartość | 0.132 | 0.332 | - | 1.98E-03 | 1.98E-03 | 1.98E-03 | 1.98E-03 | - | 4.97E-03 | 4.97E-03 | 4.97E-03 | 4.97E-03 |
| Maksymalna wartość | 0.206 | 0.517 | - | 3.09E-03 | 3.09E-03 | 3.09E-03 | 3.09E-03 | - | 7.76E-03 | 7.76E-03 | 7.76E-03 | 7.76E-03 |
| SD | 0.029 | 0.074 | - | 4.32E-04 | 4.32E-04 | 4.32E-04 | 4.32E-04 | - | 1.08E-03 | 1.08E-03 | 1.08E-03 | 1.08E-03 |
| Analiza wariancji | 0.001 | 0.014 | - | 1.87E-07 | 1.87E-07 | 1.87E-07 | 1.87E-07 | - | 1.18E-06 | 1.18E-06 | 1.18E-06 | 1.18E-06 |

SD – odchylenie standardowe

### 4.5.2. Słodkie produkty zbożowe jako źródło sodu i soli w diecie dzieci w wieku 1–14 lat

Udział analizowanych słodkich produktów zbożowych w spożyciu sodu i soli w dietach dzieci zależał od: (1) średniej zawartości sodu i soli w produktach, (2) zalecanej porcji produktu do spożycia oraz (3) dziennego poziomu wystarczającego spożycia sodu. Produkty inne niż ciastka dla niemowląt i małych dzieci nie są zalecane dla dzieci poniżej 1. roku życia, dlatego były one jedyną analizowaną grupą produktów w tej grupie wiekowej. Wraz z jedną spożytą porcją, ciastka dla niemowląt i małych dzieci dostarczały 0,4% AI w grupie wiekowej poniżej 1. roku życia. U dzieci powyżej 1. roku życia, największych ilości sodu (i soli) z jedną porcją produktu dostarczały głównie ($p<0,05$) wyroby cukiernicze i pieczywo (8,93–14,3% AI), następnie płatki śniadaniowe (2,67–4,64% AI) i ciastka (1,36–1,79% AI), podczas gdy pozostałe produkty dostarczały poniżej 0,4% AI. Dla dzieci w wieku 1–3 lat, wyroby cukiernicze i pieczywo dostarczały 73% sodu, płatki śniadaniowe 24% sodu, wafle ryżowe 2% sodu, podczas gdy ciastka dla niemowląt i małych dzieci oraz batony zbożowe dostarczały po 1% sodu. W przypadku dzieci w wieku 4–6 i 7–10 lat, wyroby cukiernicze i piekarnicze dostarczały 66% sodu, płatki śniadaniowe 21% sodu, ciastka 10% sodu, podczas gdy batony zbożowe i wafle ryżowe dostarczały po 1% sodu. W diecie dzieci w wieku 11–14 lat, wyroby cukiernicze i piekarnicze dostarczały 69% sodu, płatki śniadaniowe 17% sodu, ciastka 12% sodu, a batony zbożowe i wafle ryżowe dostarczały po 1% sodu (Tabela 11). W badaniu Marrero i in. (2014) ciastka, ciasta, bułeczki i pączki stanowiły 5% dziennego pobrania sodu, natomiast płatki śniadaniowe 6% dziennego pobrania sodu wśród dzieci w wieku 5–17 lat. W badaniu Grimes i in. (2017) ciasta, muffiny, bułeczki i desery w formie ciast dostarczały 5,2%, gotowe płatki śniadaniowe 3,3%, a biszkopty 1,7% dziennego pobrania sodu w diecie dzieci w wieku 8–12 lat. W badaniu O'Halloran i in. (2016) płatki śniadaniowe i batony zbożowe dostarczały około 4% całkowitego spożycia sodu w diecie 3,5-letnich dzieci. W grupie produktów zbożowych głównymi źródłami sodu w diecie dzieci są pieczywo i produkty piekarnicze, ale słodkie przekąski są często spożywane między posiłkami i poza kontrolą rodziców, co stanowi dodatkowe i nieoczywiste źródło sodu (Marrero i in. 2014; Grimes i in. 2017; O'Halloran i in. 2016). Chociaż ich udział w całkowitym spożyciu sodu w diecie jest niższy niż w przypadku produktów słonych, zmiany w tej kategorii produktów mogą mieć namacalny wpływ na ogólne narażenie dzieci na sód, zwłaszcza biorąc pod uwagę częstotliwość spożycia i marketing tych produktów skierowany do młodych konsumentów (Grimes i in. 2017; Martini i in. 2022).

**Tabela 11.** Udział jednej średniej porcji słodkich produktów zbożowych w podaży sodu (Na) w diecie dzieci

| | **Grupa wiekowa** | | | | |
|---|---|---|---|---|---|
| | **< 1** | **1 – 3** | **4 – 6** | **7 – 10** | **11 – 14** |
| **Wystarczające spożycie (AI) sodu** | **370 mg** | **750 mg** | **1000 mg** | **1200 mg** | **1300 mg** |
| **Średni udział słodkich produktów zbożowych w pokryciu dziennego AI sodu [1], %** | | | | | |
| Płatki śniadaniowe | - | 4.64 [b] | 3.47 [b] | 2.89 [b] | 2.67 [b] |
| Wyroby cukiernicze i piekarnicze | - | 14.3 [a] | 10.7 [a] | 8.93 [a] | 10.7 [a] |
| Ciastka | - | - | 1.63 [c] | 1.36 [c] | 1.79 [c] |
| Ciastka dla niemowląt i małych dzieci | 0.40 [a] | 0.20 [d] | - | - | - |
| Batony zbożowe | - | 0.21 [d] | 0.20 [d] | 0.17 [e] | 0.15 [e] |
| Wafle ryżowe | - | 0.31 [c] | 0.23 [d] | 0.19 [d] | 0.18 [d] |
| **Udział w podaży Na, % [2]** | | | | | |
| Płatki śniadaniowe | 0 | 24 | 21 | 21 | 17 |
| Wyroby cukiernicze i piekarnicze | 0 | 73 | 66 | 66 | 69 |
| Ciastka | 0 | 0 | 10 | 10 | 12 |
| Ciastka dla niemowląt i małych dzieci | 100 | 1 | 0 | 0 | 0 |
| Batony zbożowe | 0 | 1 | 1 | 1 | 1 |
| Wafle ryżowe | 0 | 2 | 1 | 1 | 1 |

[1] Rychlik i in. (2024); [2] dzienne spożycie produktów zbożowych o słodkim smaku przyjęto jako 100%; AI – wystarczające spożycie; [a, b, c, d, e] – wartości oznaczone różnymi indeksami górnymi w tych samych wierszach różnią się istotnie przy $p<0,05$ zgodnie z testem Duncana.

Podsumowując, wyniki uzyskane w publikacji **P5** pokazują, że wśród analizowanych słodkich produktów zbożowych, wyroby cukiernicze i piekarnicze były istotnym źródłem sodu i soli dla dzieci w wieku 1–14 lat – wszystkie zawierały dodatek soli. Chociaż wszystkie analizowane w pracy produkty są uważane za „słodkie” i nazywane „słodkimi”, większość z nich zawierała dodatek soli i może dostarczać dzieciom znacznych ilości sodu. **Praca ta jest istotna, ponieważ identyfikuje i ilościowo ocenia niedostrzegane dotąd źródła sodu w słodkich produktach zbożowych, dostarczając kluczowych danych dla reformulacji produktów, edukacji żywieniowej oraz działań profilaktycznych w zakresie zdrowia publicznego.** Produkty takie jak ciastka dla niemowląt i małych dzieci, sezamki i wafle ryżowe okazują się być lepszym wyborem, ponieważ zawierają mniej sodu w porównaniu z innymi analizowanymi produktami, a ponadto większość z nich nie zawiera dodatku soli w swoich recepturach.

## 4.6. Ocena zawartości sodu w wybranych biszkoptach z mlecznym nadzieniem oraz oszacowanie pobrania sodu ze średnią porcją biszkoptów z mlecznym nadzieniem przez dzieci w wieku przedszkolnym (4–6 lat)

Słodkie przekąski, takie jak biszkopty z mlecznym nadzieniem, potocznie nazywane mlecznymi kanapkami, są powszechnym elementem diety zarówno dorosłych, jak i dzieci (Kmiecik i in. 2016). Z uwagi na ich powszechność w jadłospisach oraz wysokie wymagania żywieniowe dzieci w wieku przedszkolnym, powinny być jak najlepszej jakości (Orkusz i Włodarczyk, 2014). Konsumenci postrzegają mleczne kanapki jako produkty o wysokiej wartości pokarmowej, ponieważ reklamy przedstawiają je jako źródło wapnia i pożywną przekąskę między posiłkami. Rodzice, którzy chcą kupić wartościowy produkt dla swoich dzieci, ale nie mają wystarczającej wiedzy na temat żywienia, mogą błędnie interpretować przekaz marketingowy dotyczący mlecznych kanapek i dokonywać niewłaściwych wyborów żywieniowych. Dodatkowo należy pamiętać, że tego typu produkty są źródłem cukrów prostych, dostarczają sporo kalorii, a udział mikroelementów w ich składzie może być ograniczony (zależny od składu i fortyfikacji). Poza tym, mimo ich słodkiego smaku, bardzo często zawierają w swoim składzie sól, która może wpływać na zwiększenie podaży sodu z dietą, co w nadmiarze i w dłuższej perspektywie czasu zwiększa ryzyko nadciśnienia tętniczego (Eckel i in. 2014) i sprzyja wystąpieniu otyłości u dzieci (Kwiecień i in. 2017). Celem pracy badawczej **P6**, pt. *„Milk slices as a source of macroelements and microelements in the diet of pre-schoolers”*, była ocena zawartości sodu w wybranych biszkoptach z mlecznym nadzieniem oraz oszacowanie pobrania sodu ze średnią porcją biszkoptów z mlecznym nadzieniem przez dzieci w wieku przedszkolnym (4–6 lat).

### 4.6.1. Zawartość sodu w porcji mlecznych kanapek i pokrycie wystarczającego spożycia na sód

Jedna porcja (średnio 31,7 g) mlecznych kanapek zawierała 6,28–377,2 mg sodu (średnio 91,8 ± 100,9 mg), co pokrywało wystarczające spożycie sodu dla dzieci w wieku przedszkolnym (1000 mg) w 9,2% (Tabela 12). Zawartość sodu w batonach zbożowych z płatkami ryżowymi oceniona przez Agbaje i in. (2014) wynosiła 70,54–235,86 mg $kg^{-1}$, czyli znacznie mniej niż w badaniu własnym (średnio 2703 ± 2366 mg $kg^{-1}$). Z analizy etykiet biszkoptów nadziewanych kremem (n = 76) przeprowadzonej przez Dall'Asta i in. (2020)

wynika, że zawierały one 1460 $mg/kg^{-1}$ sodu (mediana). Różnica względem badania własnego może wynikać z tego, że skład podany na etykiecie jest często niższy niż faktycznie oznaczony laboratoryjnie, a także z różnic pomiędzy składem produktów dostępnych w sklepach w Polsce i we Włoszech. Według Afroza i in. (2025), na etykietach 40% przetworzonych i wysokoprzetworzonych produktów widniała niższa zawartość sodu niż wynikało z analizy laboratoryjnej, ale w kategorii „cakes and sponges" (biszkopty i ciasta biszkoptowe) 50% badanych produktów wskazywało wyższą zawartość sodu na etykiecie względem zmierzonej. Przegląd literatury naukowej pokazuje, że u dzieci w wieku przedszkolnym i wczesnoszkolnym, pomimo funkcjonalnego dojrzewania nerek (Seely, 2017), nadal należy zwracać uwagę na zawartość sodu w diecie ze względu na możliwość wystąpienia nadciśnienia tętniczego w wieku dorosłym (Lava i in. 2015; Gowrishankar i in. 2020).

**Tabela 12**. Zawartość sodu (Na) w 1 średniej porcji mlecznych kanapek

| n | Masa produktu (g) | Na (mg) |
|---|---|---|
| 1 | 28 | 35,53 $^{d}$ |
| 2 | 50 | 257,5 $^{k}$ |
| 3 | 30 | 21,09 $^{b}$ |
| 4 | 29 | 75,93 $^{h}$ |
| 5 | 30 | 25,27 $^{bc}$ |
| 6 | 32 | 66,12 $^{g}$ |
| 7 | 29 | 155,5 $^{j}$ |
| 8 | 32 | 60,06 $^{fg}$ |
| 9 | 29 | 95,61 $^{i}$ |
| 10 | 16 | 28,93 $^{c}$ |
| 11 | 28 | 57,62 $^{f}$ |
| 12 | 28 | 46,91 $^{e}$ |
| 13 | 40 | 377,2 $^{l}$ |
| 14 | 45 | 6,281 $^{a}$ |
| 15 | 30 | 67,39 $^{g}$ |
| Średnio | 31,7 | 91,80 |
| Min | | 6,280 |
| Max | | 377,2 |
| SD | | 100,9 |
| Wariancja | | 10183 |

SD – odchylenie standardowe; Min – wartość minimalna; Max – wartość maksymalna; $^{a, b, c,...}$ – wartości oznaczone różnymi indeksami górnymi różnią się przy p<0,05 według testu Duncana.

### 4.6.2. Pokrycie dziennego wystarczającego spożycia na sód z 1 średnią porcją mlecznych kanapek serwowanych na drugie śniadanie lub podwieczorek

Mleczne kanapki są przekąskami spożywanymi głównie podczas drugiego śniadania lub podwieczorku. Przy założeniu spożywania pięciu posiłków dziennie, przekąska podawana dzieciom w wieku przedszkolnym powinna stanowić 10% wartości energetycznej diety w drugim śniadaniu i 15% w podwieczorku (Charzewska, 2011). Jak pokazują wyniki badań własnych, porcja mlecznej kanapki spożywana podczas drugiego śniadania i podwieczorku pokrywa dzienne wystarczające spożycie sodu dla dzieci w wieku 4–6 lat, odpowiednio, w 91,8% i w 61,2% (Tabela 13). Badanie przeprowadzone w kanadyjskich przedszkolach pokazało, że dzieci w wieku 3–5 lat spożywały średnio 2,3 przekąski dziennie, co stanowiło około 22,6% pokrycia całkowitego spożycia sodu w ciągu dnia (Mireault i in. 2023). Przekąski spożywane przed południem (odpowiednik drugiego śniadania) dostarczały $130.8 \pm 157.4$ – $176.3 \pm 94.1$ mg sodu, a przekąski spożywane po południu (odpowiednik podwieczorku) dostarczały $153.6 \pm 169.7$ – $188.0 \pm 136.9$ mg sodu. Co ciekawe, wyższą zawartością sodu odznaczały się przekąski spożywane przez dzieci uczęszczające do przedszkoli, w przeciwieństwie do dzieci pozostających w domach ($p<0,05$). Lythgoe i in. (2013) zauważyli, że batoniki zbożowe przeznaczone dla dzieci mają istotnie wyższą zawartość sodu niż batoniki nie kierowane marketingowo do dzieci. To sugeruje, że niektóre batoniki mogą dostarczać znacznych ilości sodu, co w kontekście drugiego śniadania może być ważne – szczególnie, jeśli przekąska jest regularnie spożywana.

**Tabela 13**. Pobranie sodu (Na) z 1 średnią porcją mlecznej kanapki (31,7 g) oraz procentowy udział Na pobranego z 1 średnią porcją mlecznej kanapki względem AI sodu w drugim śniadaniu i podwieczorku dzieci w wieku 4–6 lat

| AI sodu (mg) | Pobranie sodu z 1 średnią porcją mlecznej kanapki (31,7 g) | Pokrycie AI sodu (%) | AI sodu z drugim śniadaniem (10%) (mg) | Pokrycie AI sodu z drugim śniadaniem (%) | AI sodu z podwieczorkiem (15%) (mg) | Pokrycie AI sodu z podwieczorkiem (%) |
|---|---|---|---|---|---|---|
| 1000 | 91,8 | 9,2 | 100 | 91,8 | 150 | 61,2 |

AI – wystarczające spożycie

Podsumowując, wyniki uzyskane w publikacji **P6** pokazują, że porcja mlecznych kanapek pokrywa dzienne wystarczające spożycie sodu dla dzieci w wieku przedszkolnym w niewielkim stopniu (9,2%). Jednak spożywanie ich zgodnie z rekomendacjami producentów, na drugie śniadanie lub podwieczorek, powoduje pokrycie dziennego wystarczającego spożycia w odpowiednio 92% lub 61%, co przy regularnym występowaniu w diecie oraz jednoczesnym spożyciu innych produktów dostarczających znacznych ilości sodu, może przyczyniać się do przekroczenia limitów. Aby zwiększyć wartość odżywczą drugiego śniadania lub podwieczorku zawierającego mleczną kanapkę można zaproponować dodatkowo porcję owoców lub jogurtu. **Praca ta jest istotna, ponieważ dostarcza rzetelnej, ilościowej oceny udziału popularnych mlecznych kanapek w podaży sodu w diecie dzieci w wieku przedszkolnym, ujawniając ryzyko ich nadmiernego spożycia w kontekście zaleceń producentów oraz potrzebę świadomej reformulacji i właściwego komponowania posiłków.** Należy zachęcać dzieci do spożywania przekąsek o niskim stopniu przetworzenia, dostarczając młodym organizmom więcej wartości odżywczych, jednocześnie utrzymując niską podaż sodu.

# 5. Podsumowanie i wnioski

Weryfikowana w ramach niniejszej pracy hipoteza badawcza zakładała, że produkty zbożowe mogą być źródłem sodu i soli w diecie dzieci. Hipoteza ta została potwierdzona. Przeprowadzone badania dowodzą, że sól w produktach zbożowych, zarówno dodawana na etapie produkcji, jak i podczas gotowania, stanowi istotne źródło sodu w diecie dzieci. Głównym źródłem sodu jest chleb, ale również wyroby cukiernicze i piekarnicze, co zostało udowodnione zarówno w tej pracy, jak i we wcześniej opublikowanych badaniach innych autorów. Z uwagi na powszechny dodatek soli do tych produktów oraz ich wysokie spożycie, przyczyniają się one w największym stopniu do pokrycia limitów ustalonych dla soli. W tej pracy nie zanotowano nadmiernego pobrania sodu z chlebem, prawdopodobnie dlatego, że za porcję przyjęto ilość rekomendowaną, a nie faktycznie spożywaną. Chociaż inne analizowane w tej pracy słodkie produkty zbożowe nie stanowią znaczącego odsetka podaży sodu, to spożywane z innymi produktami bogatymi w sód oraz konsumowane w nadmiernych ilościach również mogą przyczyniać się do nadmiernego pobrania sodu z żywności. Sód odgrywa istotną rolę w homeostazie organizmu, ma znaczenie w przygotowywaniu, przetwarzaniu i konserwowaniu żywności, ale podobnie jak w przypadku innych składników pokarmowych, jego nadmierne spożycie wiąże się z poważnymi problemami zdrowotnymi.

W pracy wykazano, że dodatek soli do wody w której gotuje się makaron istotnie zwiększa: zawartość sodu w ugotowanym makaronie, pobranie sodu z porcją makaronu oraz stopień wchłaniania sodu w przewodzie pokarmowym w porównaniu do makaronu niesolonego. Z tego względu rekomenduje się, aby nie dosalać wody, w której gotuje się makaron, a danie doprawiać poprzez dodatek ziół i przypraw do sosów, z którymi makaron jest podawany. Co więcej, płukanie makaronu po ugotowaniu nie przywraca jego wyjściowej zawartości sodu (sprzed posolenia).

Rezygnacja z dosalania posiłków, lub zdecydowana redukcja soli i zastąpienie jej ziołami lub przyprawami, które samodzielnie przygotowuje się dzieciom w domu jest istotna, ponieważ dzięki temu posiada się realny wpływ na to, jakich ilości sodu posiłek dziecku dostarczy. Jest to jedna ze strategii zmniejszających ryzyko wystąpienia chorób dietozależnych, związanych z nadmierną podażą sodu – zarówno w dzieciństwie, jak i w dorosłości.

Uzyskane wyniki stanowiły podstawę do wyciągnięcia następujących wniosków, które potwierdzają zasadność przyjętej hipotezy badawczej.

1. Najbardziej efektywną strategią ograniczania podaży sodu na poziomie populacyjnym jest kompleksowe i wielopłaszczyznowe podejście, obejmujące reformulację produktów spożywczych (zwłaszcza zbożowych), stopniową redukcję zawartości soli w żywności, edukację konsumentów oraz odpowiednie oznakowanie produktów, co pozwoli na poprawę stanu zdrowia publicznego bez istotnego pogorszenia akceptacji sensorycznej żywności.
2. Sposób obróbki kulinarnej makaronu w istotnym stopniu modyfikuje wartość odżywczą produktu końcowego, szczególnie w odniesieniu do zawartości sodu. Gotowanie makaronu w wodzie bez dodatku soli i bez płukania po ugotowaniu pozwala na ograniczenie podaży sodu, co czyni tę metodę najkorzystniejszą z punktu widzenia żywienia i profilaktyki dietozależnych chorób cywilizacyjnych.
3. Metoda gotowania makaronu – w wodzie z dodatkiem soli lub bez soli – znacząco wpływa na wchłanianie sodu podczas trawienia; stopień wchłaniania sodu z makaronu jest dodatnio skorelowany z zawartością sodu w produkcie
4. Zawartość sodu i soli w chlebie jest przede wszystkim determinowana ilością dodanej soli podczas produkcji, a nie naturalną zawartością sodu w mące, co podkreśla znaczenie technologii wypieku w kształtowaniu wartości odżywczej produktów zbożowych. Spożycie chleba w zalecanych porcjach dla dzieci nie prowadzi do przekroczenia dziennego zalecanego spożycia soli; jednak częste spożywanie większych niż zalecane porcji chleba oraz innych produktów zbożowych o wysokiej zawartości soli może znacząco zwiększać całkowite spożycie sodu w diecie dzieci, co wymaga uwzględnienia w działaniach promujących zdrowe żywienie.
5. Słodkie produkty zbożowe, pomimo powszechnej percepcji jako źródło głównie cukrów, stanowią również istotne źródło sodu i soli w diecie dzieci.
6. Analizowane biszkoptowe batoniki typu mleczne kanapki, mimo powszechnego postrzegania ich jako produktów o wysokiej wartości pokarmowej, traktowania jako zamiennika pełnowartościowych produktów mlecznych oraz elementu diety wspierającej prawidłowy rozwój dziecka, w jednej porcji pokrywają dzienne wystarczające spożycie sodu dla dzieci w wieku przedszkolnym w niewielkim stopniu, ale spożywane regularnie na śniadanie lub podwieczorek mogą przyczyniać się do przekraczania limitów.

# 6. Wartość aplikacyjna badań

Przedstawione badania ukazują praktyczne znaczenie wybranych produktów zbożowych w ocenie podaży sodu w diecie dzieci, podkreślając jednocześnie rolę sposobu ich obróbki kulinarnej oraz porcji spożycia. Wskazują one, że żywność powszechnie występująca w diecie dzieci – m.in. makaron, chleb, słodkie produkty zbożowe – może mieć istotny wpływ na dostarczanie sodu, przy czym wielkość jej podaży można modyfikować poprzez wybór odpowiedniej technologii przygotowania posiłków. Przykładowo, odpowiednia technika gotowania makaronu, np. ograniczenie dodatku soli i nie płukanie go po ugotowaniu, pozwala kontrolować zawartość sodu w diecie. Istotnym wnioskiem z analiz jest także rola kontroli porcji oraz monitorowania zawartości soli w produktach zbożowych spożywanych przez dzieci, które przy spożyciu zgodnym z zaleceniami nie muszą dostarczać nadmiaru sodu. Należy podkreślić zatem konieczność zintegrowanego podejścia: łączenia edukacji żywieniowej, odpowiednich technik kulinarnych (ograniczenie solenia), świadomego wyboru produktów niskosodowych i monitorowania porcji przez rodziców, opiekunów i osób odpowiedzialnych w instytucjach żywienia zbiorowego (dietetyków, intendentów) oraz właściwych decyzji producentów żywności. Ważne jest wyznaczanie limitów sodu, reformulacja produktów dla dzieci oraz przejrzysta komunikacja wartości pokarmowej na opakowaniach. W ujęciu aplikacyjnym stanowi to solidną podstawę do opracowywania zaleceń dietetycznych i zdrowotnych w kontekście żywienia dzieci w domach i w placówkach oświatowych, jednocześnie wskazując, że pozornie niewielkie zmiany technologiczne i żywieniowe mogą realnie wpływać na jakość diety na poziomie populacyjnym.

# 7. *Novum*

Cykl przeprowadzonych badań wnosi istotny wkład do dyscypliny, koncentrując się na problematyce pobrania sodu z produktów zbożowych w dietach dzieci. Nowością tych prac jest zintegrowane ujęcie zagadnienia, obejmujące jednocześnie: (1) analizę zawartości sodu w wybranych produktach zbożowych spożywanych przez najmłodszych konsumentów, (2) wpływ obróbki kulinarnej na rzeczywiste wchłanianie składników mineralnych, (3) ocenę konsekwencji zdrowotno-żywieniowych oraz (4) analizę kontekstu regulacyjno-interwencyjnego. Połączenie analiz chemicznych, symulowanych procesów trawienia oraz perspektywy zdrowia publicznego stanowi podejście rzadko spotykane w literaturze, w której badania te zwykle prowadzone są w sposób wycinkowy.

W zakresie oceny spożycia sodu *novum* stanowią badania pokazujące, że produkty zwyczajowo kojarzone z wysoką zawartością soli nie stanowią rzeczywistego problemu żywieniowego, o ile spożywane są w rekomendowanych dla grupy wiekowej ilościach. Wynik ten wskazuje na potrzebę konstruowania zaleceń żywieniowych w oparciu o realną zawartość sodu w typowych porcjach. Z kolei analiza słodkich produktów zbożowych identyfikuje je jako nieoczywiste i niedoceniane źródło sodu w dietach dzieci, pokazując konieczność rewizji systemów oznakowania żywności na etykietach i klasyfikowania żywności jako problematycznej pod względem zawartości soli. Niektóre z nich nie są jednoznacznie klasyfikowane jako „zdrowe" lub „niezdrowe" i przez to były dotąd pomijane w analizach żywieniowych dzieci.

Nowatorski charakter mają również badania dotyczące stopnia wchłaniania sodu, w których analizowano wpływ dodania soli do wody podczas gotowania makaronu na stopień absorpcji sodu w przewodzie pokarmowym. Jest to pierwsza dostępna publikacja, która nie ogranicza się wyłącznie do oceny zawartości sodu w makaronach po obróbce, co otwiera drogę do formułowania zaleceń kulinarnych opartych na mechanizmach biologicznych, a nie tylko na analizie składu surowca i produktu.

Komplementarnym elementem całego cyklu jest publikacja przeglądowa dotycząca strategii redukcji sodu, która jako jedna z nielicznych łączy technologiczne możliwości reformulacji produktów z oceną efektywności działań zdrowia publicznego. Wpisuje to prowadzone badania w szerszy kontekst polityk żywieniowych, stanowiąc podstawę do opracowania praktycznych zaleceń dla przemysłu spożywczego i instytucji państwowych.

Podsumowując, zaprezentowane badania wprowadzają nowe spojrzenie na problem spożycia sodu przez dzieci, przesuwając akcent z ogólnych deklaracji składu żywności na: rekomendowaną konsumpcję, wchłanianie, nieoczywiste źródła sodu oraz praktyczne skutki reformulacji i interwencji zdrowotnych. To wieloaspektowe ujęcie czyni cykl prac wartościowym zarówno z perspektywy naukowej, jak i praktyki żywieniowej oraz zdrowia publicznego.

# 8. Kierunki przyszłych badań naukowych

Mimo rosnącej świadomości żywieniowej w obszarze diety dzieci, aktualne badania dotyczące produktów zbożowych wskazują na szereg luk, które ograniczają możliwość formułowania precyzyjnych zaleceń zdrowotnych. Jednym z kluczowych wyzwań jest brak danych dotyczących rzeczywistego spożycia sodu wynikającego nie tylko ze składu ocenianych produktów, ale również z praktyk domowych i placówkowych. Wiele dotychczasowych prac opiera ocenę podaży soli na wartościach deklarowanych przez producentów lub teoretycznych porcjach, co nie zawsze dokładnie odzwierciedla realne nawyki żywieniowe. Konieczne są zatem badania terenowe, pozwalające na weryfikację różnic między spożyciem deklarowanym a rzeczywistym. Dane te mogą stanowić podstawę do oceny ryzyka zdrowotnego i ustalania odpowiednich limitów sodu w produktach przeznaczonych dla dzieci.

Ważnym, rozwojowym obszarem badań są również interwencje skupione na reformulacji żywności, ponieważ część produktów zbożowych, szczególnie dedykowanych najmłodszym, charakteryzuje się wysoką zawartością sodu pomimo ich słodkiego smaku. Przyszłe badania powinny nie tylko analizować możliwość obniżania zawartości soli w tych produktach, lecz także oceniać konsekwencje sensoryczne i technologiczne takich zmian. Wymaga to weryfikacji akceptacji konsumenckiej, ekonomicznych skutków potencjalnej kompensacji solą z innych źródeł oraz wpływu na cechy technologiczne produktów, w tym trwałość i bezpieczeństwo mikrobiologiczne. Równolegle zasadne wydają się badania nad alternatywnymi składnikami smakowymi i zamiennikami soli, które mogą ograniczyć jej udział bez obniżenia atrakcyjności sensorycznej produktów zbożowych.

W kontekście przyszłych badań naukowych zasadne jest zwrócenie uwagi na podwójną rolę soli kuchennej w diecie – jako głównego źródła sodu, ale również istotnego nośnika jodu, w który jest ona obligatoryjnie fortyfikowana. Przy niskim i niewystarczającym spożyciu ryb morskich w populacji Polski sól kuchenna pozostaje podstawowym źródłem jodu dla znacznej części społeczeństwa. Z jednej strony aktualne zalecenia żywieniowe słusznie podkreślają konieczność ograniczania spożycia soli, zwłaszcza u dzieci, ze względu na ryzyko nadmiernej podaży sodu, z drugiej jednak – jej odpowiednie spożycie może warunkować pokrycie dziennego zapotrzebowania na jod. Przyszłe badania powinny koncentrować się na ocenie bilansu korzyści i zagrożeń wynikających z redukcji soli w diecie dzieci w kontekście zaopatrzenia populacji w jod, a także na opracowaniu skutecznych strategii żywieniowych i edukacyjnych promujących naturalne źródła jodu, w szczególności ryby morskie.

Kolejny istotny kierunek badań dotyczy stopnia wchłaniania sodu w zależności od sposobu obróbki kulinarnej. Dotychczasowe prace oparte głównie na modelach *in vitro* wskazują, że zwłaszcza gotowanie może istotnie wpływać na zawartość i stopień wchłaniania mikroelementów, w tym sodu. Konieczne są jednak badania *in vivo,* obejmujące różne grupy wiekowe, które umożliwiłyby opracowanie zaleceń kulinarnych opartych nie tylko na składzie produktów, ale na ich rzeczywistym wpływie metabolicznym. W połączeniu z analizą szerokiego repertuaru produktów zbożowych (np. ryż, kasze, płatki, produkty fortyfikowane), badania te mogłyby stanowić cenne źródło wiedzy zarówno dla dietetyków, technologów żywności, jak i producentów żywności funkcjonalnej.

Z perspektywy zdrowia publicznego nie można również pominąć badań nad skutecznością strategii obniżania spożycia soli w populacji dzieci. Dotychczasowe zalecenia są najczęściej tworzone na podstawie analiz teoretycznych, natomiast brakuje danych, które weryfikowałyby realny efekt wdrażania limitów sodu w placówkach edukacyjnych, czy skuteczność kampanii informacyjnych. Ocena działań polityki żywieniowej, w połączeniu z modelowaniem ekonomicznym redukcji spożycia sodu, może stanowić fundament dla tworzenia skutecznych programów profilaktycznych.

Podsumowując, dalsze badania dotyczące produktów zbożowych w diecie dzieci powinny zmierzać w kierunku integracji podejść konsumenckich, technologicznych, metabolicznych, ekonomicznych oraz politycznych. Dopiero połączenie tych perspektyw pozwoli na precyzyjne formułowanie kolejnych rekomendacji, które będą jednocześnie naukowo uzasadnione, technologicznie wykonalne i skuteczne w praktyce zdrowia publicznego.

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# 10. Kopie opublikowanych prac

*nutrients*

*Review*

# Initiatives to Reduce the Content of Sodium in Food Products and Meals and Improve the Population's Health

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**Abstract:** Table salt is the main source of sodium (Na) in the human diet. Excessive supply of Na in a diet is strongly linked to many non-communicable human diseases, such as hypertension, obesity and stomach cancer. The World Health Organization recommends that daily intake of salt in adult diets should be kept below 5 g/person/day, which corresponds to 2 g Na/person/day. However, on average, adults consume about 9–10 g/person/day, and children and young people about 7–8 g/person/day. Initiatives to reduce salt intake include modifications of food composition in collaboration with the food industry, education of consumers, salt marking on foodstuff labels and taxation of salt. A need also exists to educate society so that they choose low-sodium products. In view of the food technology and amount of salt intake, the most important and the easiest change to make is to reduce the content of salt in baked goods. This paper analyses the results of surveys regarding strategies to reduce salt content in food products and considers multifaceted initiatives to reduce salt intake as a possible efficient method of improving the population's health status.

**Keywords:** salt; salt intake reduction; sodium; cereal products; food education; non-communicable diseases; hypertension; sodium sensitivity; food manufacturing; salt substitutes



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## 1. Introduction

Recently, we have observed a growing consumer interest in food quality and safety as well as the effect it has on human health. Consumers wish food was healthier and contained fewer ingredients believed to have adverse impact on health [1]. Sodium chloride plays a significant role in food processing, having several functions such as: sensory (shaping taste), texture-forming (affecting water/fat binding capacity) and bacteriostatic (inhibiting microbial growth) functions [2].

According to Liem [3], salty taste preference develops due to multiple exposures to salty foods. Infants develop salty taste gradually. Most likely, below three months of age, they are incapable of tasting salt. However, when infants start recognising saltiness, this becomes their preferred taste. Similar to their preference for sweet taste, children prefer salt at higher concentrations than adults do [3].

Salt (table salt, sodium chloride, NaCl) consists of sodium ($Na^+$) and chloride ($Cl^-$) ions. Approximately 90% of sodium and chlorides in the diet are derived from salt [4]. Since salt is commonly added to various products and dishes, sodium deficiency in the diet is very rare. By contrast, excessive sodium intake is a much more frequent problem, which increases the excretion of calcium with urine and aggravates the risk of hypertension [5]. When 1 g of Na is consumed, as much as 26 mg of Ca will be excreted with urine, which is particularly important for the commonly recorded Ca deficiency in the diets of Polish people [6]. Long-term commitment to reducing Na intake is a challenge to the general population. According to Global Burden of Disease data [7], 1.89 million deaths from cardiovascular diseases (CVD) per year worldwide are associated with excessive intake of Na. A meta-analysis of studies conducted from 1946 to 2020 showed that Na reduction following applicable recommendations contributed to reduction in blood pressure by about 0.4 mmHg in normotensives and by about 4 mmHg in hypertensives [8]. The World Health Organization (WHO) recommends limiting salt intake to 5 g (2 g of sodium) per day for adults [9], whereas for food marking purposes, the reference intake of salt was determined as 6 g day [10]. The content of salt and sodium in products or diets should be calculated based on the assumption that 1 g of sodium corresponds to about 2.5 g of salt [11]. The European Commission has published a nutrition and health claims register that contains the list of claims that can be made about food. There is one permitted health claim for food with low or reduced sodium content: "Reducing consumption of sodium contributes to the maintenance of normal blood pressure" [12]. Sodium restriction recommendations concern both patients with hypertension and those who want to lead a healthy lifestyle [13].

Systematic reviews and meta-analyses imply considerable epidemiological evidence that consuming wholegrain products which supply at least dietary fibre is associated with a lower risk of developing non-communicable diseases related to the diet [14]. By contrast, cereal products supply considerable amounts of sodium, and table salt is used to prepare them. For example, added salt is technologically significant to the bread baking process. Dough with an excessively reduced salt content may tend to over ferment, and yeasts can produce too much carbon dioxide, which deteriorates the texture of baked goods [15]. Acceptance of low-salt baked goods by consumers is also essential. Consumers will not even note a slight reduction in the amount of salt in a product's formula (ca. 0.1–0.2%). The human body gradually adapts to and fully accepts less salty foods, so the amount of salt added to baked goods should be gradually reduced [16].

Many initiatives are undertaken around the world to reduce the consumption of salt [17]. These measures are a major challenge for food producers as they require time and financial expenditure to modify technological processes. While such initiatives generate costs for food manufacturing and require public money for health campaigns, they reduce the availability of unhealthy foods and may result in lower healthcare system costs for chronic diet-related diseases [17]. According to Zhang et al. [18], in the United States, reducing individual sodium intake to 2300 mg/day from the current level could potentially save $1990.9/person per year for hypertension treatment. Baked goods constitute an important source of sodium since most people eat them every day in large amounts [19–21]. This points to the need to reduce salt content in the baking industry for reasons of consumer health [22]. Our study showed that baked goods cover 48.2% of the Na requirement of an adult person [23]. Generally, bread contains relatively low levels of added salt (on average 2% of all the ingredients), but people consume considerable amounts of baked goods, which—as a result—makes up between 35% and 50% of sodium intake [15,22].

This paper analyses the results of surveys regarding strategies to reduce salt content in cereal products and considers multifaceted initiatives to reduce salt intake as a possible efficient method of improving the population's health status. The literature review was conducted in April 2023 using the PubMed, Scopus, Web of Science and Google Scholar literature databases. The databases were searched for both joint and separate instances of the keywords, e.g., "salt", "salt intake reduction", "sodium", "sodium:potassium ratio", "cereal products", "food education", "non-communicable diseases", "hypertension", "sodium sensitivity", "food manufacturing", and "salt substitutes" in both the English and Polish languages (Figure 1). The search was narrowed to papers published within the last 10 years. Texts were thoroughly analysed with a view to selecting the most pertinent publications. Based on the titles and synopses, articles unrelated to the substantive criteria were excluded, and the remaining original and review papers were intensely analysed to identify the most pertinent publications. Ultimately, a total of 343 publications were reviewed, of which 166 were used: 72 research reports and 94 reviews and meta-analyses (Figure 1). In this monograph, 'salt' refers to sodium chloride only.

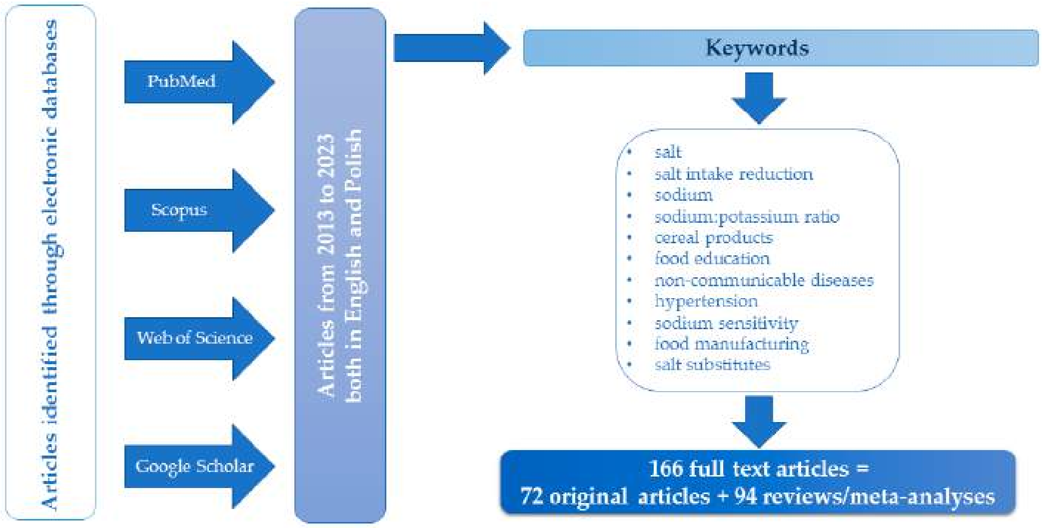


**Figure 1.** Research strategy employed in the review of available literature.

## 2. Perception of Salty Taste, Salt Craving, and Sodium Sensitivity

Taste bud cells, intracellular signals and signal pathways responsible for perceiving salty taste have still not been fully explored [24,25]; however, how the sense of taste detects salt has been intensively investigated. Detection of salt by the sense of taste is of fundamental importance for the intake of salt and tissue homeostasis [26]. Nomura et al. [27] identified taste cells responsible for $Na^+$-selective, attractive components of salty taste and for intracellular signal transduction. The above-quoted authors reported that the amiloride-sensitive epithelial sodium channel (ENaC) used as a salt receptor is co-expressed with the voltage-gated channels releasing adenosino-5′-triphosphate (ATP)-calcium homeostasis modulator 1/3 (CALHM1/3) in a subset of taste cells, and these cells mediate in amiloride-sensitive transduction of salty taste. It was demonstrated that components sensitive and insensitive to amiloride differ in terms of being selective to salt (the amiloride-sensitive component is NaCl-selective in relation to potassium chloride (KCl) and that they are mediated by various cells within a taste bud (the amiloride-sensitive component is restricted to the front part of the tongue) [26]. In order to control the correct intake of sodium, many mammals are equipped with two salt tasting mechanisms: sodium taste and high-salt taste [25].

The ions of $Na^+$ in the mouth find their way into taste receptor cells through ENaC channels (without changing the intracellular concentration of $Ca^{2+}$), leading to suprathreshold membrane depolarisation, generating action potentials, creating a channel synapse with afferent neurons, which involves a voltage-gated channel releasing neurotransmitters that comprise CALHM1 and CALHM3—CALHM1/3. The CALHM1/3 channels open in response to strong membrane depolarisation and release ATP to afferent nerve fibres (Figure 2). Thus, CALHM1/3 channels mediate in puringenic neurotransmission of the sodium taste. Salty cells can be unambiguously identified owing to the co-expression of CALHM1/3 and ENaC only, which is required for amiloride-sensitive transduction of salty taste. All sodium taste signalling stages depend on voltage and not on $Ca^{2+}$ signals. The elimination of ENaC in CALHM1-expressing cells, as well as global CALHM3 deletion, abolishes amiloride-sensitive neural responses and attenuates behavioural attraction to NaCl [27].

Perception disorders accompanying various medical conditions are deemed a disorder of taste receptors and can be caused by an infection spreading to cranial nerves responsible for transmitting taste; this was found, for instance, in COVID-19 patients who reported hypersensitivity to salty taste [28]. Mice deprived of the gene responsible for synthesising Engrailed-2 (En2—transcription factor critical to the development of neurons) showed a sensory disorder with a measurable influence on the perception of taste and, in particular, hypersensitivity to salty taste [29]. Salt craving, also referred to as sodium appetite, is mostly regulated by the hypothalamus and periventricular neurons [30].

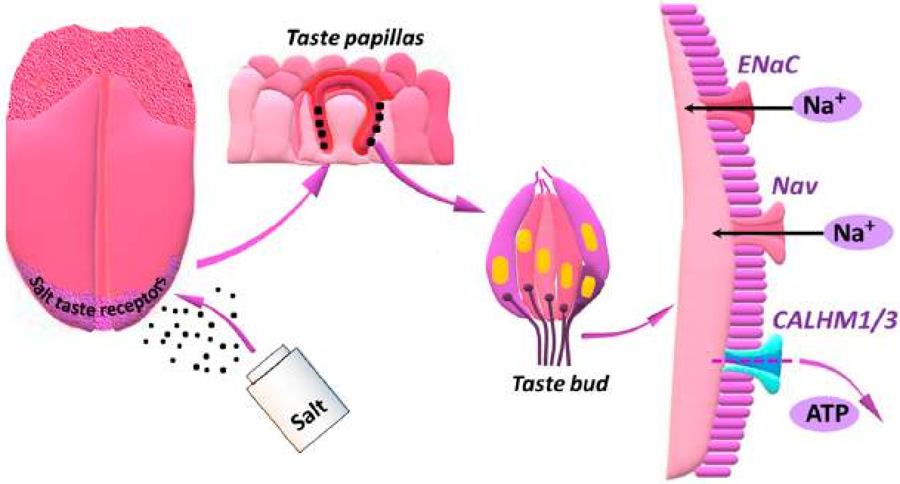


**Figure 2.** Cells and signal transduction for salty taste. ENaC—epithelial sodium channel; CALHM1/3—calcium homeostasis modulator 1/3; ATP—adenosine-5′-triphosphate; P2 × 2/3—ATP receptors.

In the course of individual development, the foliate papillae in the mucous membrane are reduced, which leads to a partial loss of taste sensitivity. It was demonstrated that, as we age, the number of taste buds is reduced even to about 30% of the starting value [31]. In parallel epithelial keratinisation progresses, which significantly affects the function of the sense of taste. Such dysfunction can also result from damage to the taste pathway in the nervous system. It was demonstrated that irregularities in the areas of the brain critical to processing olfactory information could be the main reason for dysosmia in the elderly population [32]. It is estimated that smell disorders occur in 50% of COVID-19 patients [33].

Persons experiencing blood pressure fluctuations under the influence of sodium in the diet are often referred to as 'sodium-sensitive'. Sensitivity to sodium is more frequent in people who have hypertension (30–50% of cases compared to 15–25% cases without hypertension), obese, suffering from diabetes, elderly, prematurely born, SGA babies (Small for Gestational Age), Afro-Americans, people with the metabolic syndrome and women [34–36]. The wide-ranging international study INTERSALT, conducted at 52 centres in 32 countries, corroborated the correlation between the amount of excreted sodium (being a measure of daily intake of this element) and the blood pressure value [37]. However, at the same time, genetic conditions can have an impact on individual sensitivity to sodium [38], so an excess of sodium in the diet does not increase the risk of developing hypertension to the same extent for everyone, which could explain why different populations have different sensitivity to salt [39]. The kidneys are one of the main organs destroyed by hypertension. In contrast, it is commonly believed that renal disorder plays a central role in the pathogenesis of hypertension in sodium-sensitive patients [35]. Furthermore, low weight at birth (<1000 g) and preterm birth increase the risk of hypertension for adults [40]. Interestingly, those who are sensitive to sodium show a stronger reaction to reducing salt in the diet than those resistant to sodium [4]. The diets of most sodium-resistant people can be rich in salt with no risk of developing salt-induced hypertension [41].

A complete and efficient treatment-supporting diet now recommended to overweight, hypertensive, hypercholesterolemic and hyperlipidaemic patients is DASH (Dietary Approaches to Stop Hypertension). Its main assumptions include at least four or five meals a day composed of unprocessed fruits and vegetables, cereal products, low-fat dairies, fish and nuts. The total supply of salt with the DASH diet should not exceed 2300 mg sodium/day [42]. For DASH users, salt intake increased up to 8.8 g/day did not significantly increase their blood pressure levels [41].

## 3. Actual versus Recommended Intake of Sodium in Various Populations

People generally know they consume too much salt but are not aware that they exceed the recommended intake more than two times [43]. Currently, in European countries, the average intake of salt by women is 7.3–10 g/day, and by men, 9.4–13.3 g/day [44], which is 1.5–2.7 times higher than the recommended daily intake. This may be due to the lack of awareness about sodium being present in food products consumed even more than once a day, such as bread and other cereal products [45]. Such a high intake of salt can contribute to the increased number of hypertensive patients in Poland [13].

According to the WHO Sodium Intake Reduction Report [17] and involving data from Global Burden Disease report [7], on average, people consume 4310 mg sodium per day (10.78 g of salt per day), which is double the recommended amount. The WHO proposes intake <2000 mg of sodium (equivalent to <5 g of salt) per day in adults, which is required to reduce the risk of hypertension and cardiovascular diseases. The WHO regional sodium intake in 2019 estimates range from the lowest 2687 mg/day (6.2 g/day salt) in the African Region to the highest 6247 mg/day (15.6 g/day salt) in the Western Pacific Region. The estimated intake for China is 6954 mg/day sodium, which is likely to be influencing the Western Pacific Region mean.

Actual sodium intake by the WHO Member States all over the world is presented in Sodium Intake Reduction Report [17]. Average American and Canadian diets consist of, respectively, 3400 mg and 2950 mg of Na per day, far exceeding the dietary recommendations of the WHO. The average sodium content in a daily food ration in Poland was higher than in the USA and amounted to 4357 mg/day, which considerably exceeds Polish sodium intake standards [46,47]. It is estimated that Polish people consume about 11.1 g of salt per day. The situation in Germany looks better but still exceeds standards; German people consume about 3410 mg sodium (8.7 g salt) per day. The average salt intake in Ireland was 7.3 g/day. Malaysians consume approximately 4134 mg of sodium a day, while most sodium in the diet derives from ready-to-eat food and sauces [48]. However, above mentioned intakes are still lower than reported for other countries with varied diets such as Romania (5075 mg of sodium per day), Czechia (5112 mg of sodium per day), Hungary (5646 mg of sodium per day), and China (6954 mg of sodium per day). All the Member States exceed the recommendations of the WHO. Selected sodium intakes (the lowest and the highest) and salt equivalents in various countries of the world are shown in Table 1.

**Table 1.** Selected sodium (Na) intakes and salt (NaCl) equivalents in various countries of the world (WHO Member States), based on [17].

| Country | Intake of Na [mg] | NaCl Equivalent [1] [g] |
|---|---|---|
| The highest intake | | |
| China | 6954 | 17.7 |
| Hungary | 5646 | 14.3 |
| Czechia | 5112 | 13.0 |
| Bulgaria | 5087 | 12.9 |
| Croatia | 5077 | 12.9 |
| The lowest intake | | |
| Samoa | 2006 | 5.1 |
| Türkiye | 2071 | 5.3 |
| Democratic Republic of the Congo | 2236 | 5.7 |
| Estonia | 2259 | 5.7 |
| Syrian Arab Republic | 2367 | 6.0 |

[1] the content of salt and sodium in products or diets should be calculated based on the assumption that 1 g of sodium corresponds to about 2.5 g of salt [11].

Childhood and adolescence are two key periods in human life during which eating habits and preferences develop [49,50]. A limited intake of salt in childhood is likely to prevent the development of hypertension and its related consequences in adult life [51]. The intake of sodium by the infant was evaluated, for instance, in the studies by Girardet et al. [52]. Their results imply that most infants consume an excessive amount of sodium at an early stage of their lives. According to these studies, the sodium intake of infants is often higher than the values recommended by national and international guidelines, which results in about 4–8 times higher intake of sodium [53]. In the USA, using a 24-h diet reminder used in the NHANES 2011–2012 survey with 2142 children and adolescents (6–18 years old), salt consumption was 8.1 g per day [54]. In Spain, a study carried out in 2014 with 205 children between 7 and 11 years old using 24-h urine sodium excretion, reported 7.8 g of daily intake of salt [55]. In Italy, a study covered 1424 children and adolescents between 6 and 18 years old from whom 24-h urine samples were collected, finding a salt intake of 7.1 g per day [56]. Other studies carried out in Portugal [57], using dietary registration and 24-h urinary excretion, reported 2658 mg/day sodium excretion. In total, 62% of Swiss children had salt excretions above the maximum intake recommendations ($\geq$2 g for up to 6 years and $\geq$5 g per day from 7 to 16 years) [58]. On average, children and adolescents consumed from 1.6 to 1.8 mg sodium/kcal, a much higher amount than 1 mg sodium/kcal, proposed by Guenther et al. [59].

**4. Impact of Excessive and Insufficient Intake of Sodium on the Human Health**

Almost two million deaths each year are associated with excessive sodium intake [7], a well-established cause of raised blood pressure and increased risk of CVD [60,61]. Reducing sodium intake is one of the most cost-effective ways to improve health and reduce the burden of non-communicable diseases, e.g., hypertension (systolic blood pressure $\geq$ 140 mmHg and/or diastolic blood pressure $\geq$ 90 mmHg), coronary artery disease, cardiac infarction, stomach cancer, obesity, osteoporosis, increased extracellular fluid volume, oedemas, chronic renal failure and higher general mortality rate [11], as it can avert a huge number of deaths with very low costs. The WHO recommends several sodium-related best buy interventions and other measures as practical actions that should be undertaken immediately to prevent CVD and its associated costs. Globally, an estimated 2.2 million and 7 million CVD deaths could be averted by 2025 and 2030, respectively, if countries implemented the policies suggested by WHO actions. This equates to a 3.1% reduction in CVD death, globally, by 2030 [17].

Studies confirmed that a high sodium intake is the main cause of CVD. Outcomes obtained by Emmerik et al. [62] show that a high sodium intake during the first six months after birth can also trigger negative effects for health, such as raised blood pressure levels. Infants exposed to large amounts of sodium tend to prefer the salty taste and are susceptible to renal disorders in adult life. In addition, mean sodium intake was estimated for more than 2000 respondents aged between 6 and 18 years in the National Health and Nutrition Examination Survey. Schoolchildren in the USA consume 3279 mg of sodium a day, which is above the recommended level [63]. Cotter et al. [64] obtained similar results for children aged 10–12 and found that more than 90% of the students consumed more salt than was recommended. Preparing infant formula using mineral water low in sodium or provide breast milk is recommended, along with reducing salt intake with foodstuffs and avoiding adding salt in meal preparation [52].

The latest evidence points to a considerable shift In the consumption pattern of high-sodium foods during the COVID-19 pandemic in the populations of different countries [65], including processed and canned food products that are bought ahead and quick meals. The study of the French population ($n$ = 11,391) shows that, during the first wave of the pandemic, consumption of salted food surged by 28.4% [66]. Excessive sodium intake with the diet contributes to the development of chronic diseases, such as hypertension, cardiovascular diseases and kidney diseases, thus entailing a risk of occurrence or exacerbation of comorbidities after contracting COVID-19 [65]. Society should be aware that maintaining a healthy diet during quarantine or isolation is as important as infection control and preventive measures to mitigate health risks in a population [67].

Knowledge, beliefs and perceptions about salt and sodium and their role in health and illness can differ depending on the community. D'Elia [68] observed that 86% of patients were aware that excessive salt intake adversely affects human health, but only 44% of them believed it was worth reducing salt consumption. Sodium intake reduction is an important strategy for reducing high blood pressure and preventing cardiovascular diseases, both for adults [8] and children [8].

However, it was feared that reduced sodium intake would adversely affect insulin resistance, the lipid profile of blood, the level of catecholamines and cardiovascular disease risk factors and the general health status due to excessive lowering of the level of this element in the blood. Hyponatremia occurs when the concentration of sodium in blood serum is lower than 135 mmol/L. The aetiology of hyponatremia is multifaceted, and consuming poor quality foods that contain insufficient amounts of salt can be one of its causes [69]. A counterpoint to the current recommendation for low Na intake is included in the article by O'Donnell et al. [70], which suggests that a specific low Na intake target (920 mg/day) for individuals may be infeasible and have uncertain effects on other dietary factors as well as unproven effectiveness in reducing CVD. A moderate range of dietary Na (920–1840 mg/day) is not associated with increased CVD risk, but the risk of CVD increases when Na intakes exceed 2000 mg/day. It is worth noting, however, that further Na reductions to 1500 mg/day or less are not advised among high-risk groups (i.e., individuals with heart failure, diabetes, kidney disease and CVD), as such low intakes have been associated with adverse CVD outcomes [71]. It is important that high risk groups have a properly balanced diet because both too much sodium (excessive use of table salt and eating salt-rich processed foods) and extremely too little (using low sodium salt substitutes) may not be effective in reducing CVD risk [72,73]. However, the latest reviews of studies involving adults show that there is insufficient evidence to imply that reducing sodium in the diet has a negative impact on blood glucose level measurements, insulin resistance, the lipid profile of blood or catecholamine levels in interventions lasting at least four weeks [71,74].

## 5. Sources of Salt in the Human Diet

Food products with a considerable sodium chloride content include table salt and food seasoning, baked goods, cold meats and cheeses. In developed countries, excessive intake of sodium is mostly (75–80%) due to consumption of processed food and ready meals, 5–10% occurs naturally in food products that form part of the diet and the remaining 10–15% derives from salt added in cooking or on the plate [75,76]. An exception to that rule is the inhabitants of Czechia, Poland and Romania (European developed countries), for whom salt added in cooking is the most important source of sodium in the diet [77]. In many European countries, due to a lack of time, homemade meals are rare, so only a small percentage of sodium intake derives from salt added in cooking [4]. More than one-third (34%) of Swiss children reported adding salt to their meals on the plate [58], but this figure was even higher for Costa Ricans (49.4%) [78]. In the quoted study, nearly 39% of the participants said they usually add at least one pinch of salt to their meals one or two times a week; in turn, one in ten children from Costa Rica declared that they added a pinch of salt even three or four days in a week. However, reducing sodium intake by avoiding adding salt on the plate and table salt in cooking may not be particularly efficient since most sodium in the diet derives from processed foods and restaurant meals [11]. In many high-income countries, and increasingly in low- and middle-income countries, a significant proportion of sodium intake can be attributed to take-away and out-of-home foods. One of the WHO goals is to reduce sodium intake through reducing sodium in meals or snacks consumed outside of the home and even restricting the availability of saltshakers in service areas. Therefore, it is important to implement public food procurement and service policies to reduce sodium content in food served and sold. Such policies are most common in the WHO regions of the Americas, Europe and Western Pacific, and more frequently implemented in higher income groups [17]. Processed foods, such as fried chicken, pizza, tomato sauces, fried ready baked goods, sandwiches, burgers and sausages were identified as entailing the risk of diet-related diseases (such as obesity, diabetes and hypertension) due to their high content of fat and/or sodium [79]. High salt content is typical of fast foods. A typical fast food lunch consisting of a sandwich and chips and dip (usually ketchup) contains 4.5 g of salt, which corresponds to as much as 90% of the recommended intake. Another popular fast food, doner kebab, contains from 4.0 g to 8.4 g of salt, and pizza containsfrom 7.0 g to 12.8 g. So-called instant soups should also be mentioned as they contain up to 4.1 g of salt per serving [11]. Nevertheless, international restaurants still target such meals at children, adolescents, and whole families [80].

The range of sodium content in food product categories is often extreme, both very high and permissibly low. This follows clearly from the comparison of salt content in fresh products and their processed equivalents such as fresh green (string) beans vs. canned beans, raw cabbage vs. sauerkraut (fermented cabbage), tomatoes vs. ketchup, raw ham vs. prosciutto, fresh herring vs. pickled herring, and low-fat cottage cheese vs. feta cheese. Food processing is associated with a considerable increase in salt content [11]. Differences in the content of salt can also reflect the local community's eating customs and taste preferences and partly explain the wide range of the estimated global consumption of salt. Preferred consumption of products containing large amounts of salt can explain why men tend to consume (by as much as one-third) more salt than women [77]. Adolescents also eat more meat and packaged sweets and snacks than recommended, suggesting that these are the sources from which this population derives more salt than other consumer groups [3].

Traditional dishes, cultural aspects and eating habits acquired at home also contribute to increasing sodium intake with the diet. An example is the diet of Malaysians, where the main sources of sodium in the diet were soy sauce, fried rice, omelettes, nasi lemak (rice boiled in coconut milk) and roti canai [48]. Fukutome [81] reported that 15% of total salt consumption volume in Thailand is accounted for by soy sauce and sauces containing soybean paste. Another example is the traditional Mexican diet, where sodium is mostly supplied with tacos [18].

Table 2 presents the highest contribution of various food groups (bread and bakery products, cereals and grain products, dairy, meats, sauces and dressings, seafood, snacks, and vegetables, fruits, nuts and legumes) to daily salt intake in the populations around the world.

**Table 2.** Contribution of various food groups to daily salt intake using data available from Bhat et al. [82].

| Food Groups | Countries with Highest Contribution of Various Food Groups to Daily Salt Intake | % Contribution |
|---|---|---|
| Bread and bakery products | USA, Spain, Poland | 34.9–41.1 |
| Cereals and grain products | China, Brazil, Switzerland | 23.7–23.1 |
| Dairy products | New Zealand, Argentina, Poland | 15.4–14.1 |
| Meats products | USA, Finland, Poland | 31.2–30.8 |
| Sauces and dressings | Japan * | 44.3 |
| Seafood | Japan, China, Finland | 10.2–9.0 |
| Snacks | Argentina, Canada, Mexico | 6.9–5.5 |
| Vegetables, fruits, nuts and legumes | Brazil, Poland, Japan | 18.8–18.4 |

* One country (Japan) is given due to its highest contribution compared to other countries.

## 6. Cereal Products as an Important Source of Salt in the Human Diet

The significance of grains and cereal products in human nutrition is demonstrated by the fact that global food security is mostly determined by the production of cereals, which currently exceeds 2600 million tonnes [83]. Baked goods constitute an important source of sodium since nearly everyone in the world eats baked goods in large amounts [19,20]. Most of the population consumes too much salt, so limiting the intake of sodium from baked goods can contribute to improving their health status. According to Kovac and Knific [84], salt supplied by baked goods can be successfully reduced by 75% without a difference in taste. The WHO intends to collect evidence of the economic aspect of salt reduction and provide advice on eliminating technological barriers and addressing food safety concerns associated with production of high-quality, low-salt baked goods [21].

Laskowski et al. [85] reported that cereal products covered 50% of sodium requirements in Poland. Similarly, our study revealed that cereal products cover 48.8% of an adult's requirement for Na, of which as much as 48.2% is covered by bread, 0.48% by rice, 0.04% by grains and 0.04% by pasta [23]. Data is also not favourable for the British, for whom cereal products account for 33% of total sodium intake, including 17% from baked goods [86]. For example, if an adult on average eats 250 g of bread a day (equivalent to 8 pieces of bread) containing 1.2% of salt, the consumption of salt from this bread is 3.0 g, which corresponds to 50% of the recommended daily intake of salt. If the bread contains 1.6% of salt, salt consumption is 4.0 g with 250 g of bread, which constitutes 80% of the recommended daily intake of salt [87]. One piece of whole wheat or whole grain bread supplies ca. 0.5 g of salt [11].

According to Syrad et al. [88], the intake of salt from cereal products (bread, breakfast cereals, biscuits, cakes, etc.) accounts for 38% of the daily intake of salt, while the second most significant source of salt in the diet, accounting for 21% of total intake, is meat and meat products. The main sources of salt in the diets of Latvians aged 18–35 years are cereal products, meat and meat products [72]. In contrast, in Norway, meat products are the main source [73]. Americans take most sodium from sandwiches (21%) and cereal products (8%) [89]. In turn, the main source of sodium in Germany is processed food, particularly baked goods, meat, cold meats and cheeses [4], which is similar to Poland (baked goods, cold meats, and cheeses) [39]. For Swiss children, the main sources of sodium were pasta, potatoes and rice (23% of total intake), pastries (16%) and bread (16%) [58]. Among ten products deemed to be the sources of sodium in the diets of Brazilians, four were cereal products, including white bread, rice, pasta and crackers (second, third, fifth and ninth on the list, respectively) [90]. Very similar relationships were observed for the Mexican population, where processed meat was the main component responsible for daily sodium intake, followed by taco, pizza and sweet and salty baked goods [18]. By contrast, in the diets of Costa Ricans, the main sources of sodium were table salt (60%) and processed food and food seasoning (with an addition of sodium) (27.4%) [91]. In the countries of East and Central Asia (Singapore, Malaysia, Philippines, Indonesia, Thailand and Vietnam), sodium in the diet mainly derives from salt and sauces added to the food while cooking, seasoning added on the plate, processed food and snacks (fish balls, fish pancakes, bread, and pasta), as well as beverages [92]. According to available data, bread and dairy products are the main sources of salt in the Eastern Mediterranean region [21]. For instance, in Lebanon, the major dietary contributors to sodium intake among adults were found to include bread (25%), processed meat (12%) and dairy products (10%), such as cheese and labneh (strained yogurt) [93]. Similarly, in Morocco, the main contributors included cereals and cereal-based products, followed by spices and condiments, and milk and milk products [94].

Breakfast cereals, particularly processed ones, can supply considerable amounts of Na, and these products are eagerly consumed mainly by children around the world [6]. Cornflakes, which are particularly popular among Polish children, contain more than 500 mg Na per 100 g of the product (5 g Na per 1 kg). The content of this element in sweetened cereals is also high, with more than 200 mg Na per 100 g (2 g Na per 1 kg) [6]. According to the above-mentioned study, one serving of cornflakes prepared with milk (one serving size = 30 g cereal + 125 mL milk) will cover 14% of schoolchildren's requirement, supplying ca. 0.2 g of Na, whereas one serving of other cereal will cover 5–17%, depending on its type. According to Daugirdas [95], most cereals available on the market contain ca. 200 mg or even 300 mg of Na per serving, and milk also contains ca. 65 mg of Na. The analysis of the content of Na in two popular US brands of sweetened cereals indicated that, on average, they contained 4.2 g of Na per 1 kg [96], while the average content of Na in 276 analysed cereal brands in Slovenia amounted to ca. 2.3 g Na per 1 kg (228 mg Na per 100 g) [97]. Small natural amounts of Na occur only in natural cereals and bran (wheat, rye, oats, rice), with ca. 10–40 mg Na per 1 kg of dry product [6,95]. It is estimated that the content of sodium in unprocessed raw materials is low and accounts only for 10% of the daily sodium intake [75].

Table 3 presents a ranking of salt content in cereal products, including its share of daily intake in various countries. The data was compiled for seven countries representing four different continents. Rankings of cereal products differ since their consumption depends on people's eating habits in a specific country and cultural customs determining consumption. However, four out of seven countries put baked goods (including bread and rolls) first in the ranking, and their share of daily salt intake was the highest in Latvia (67%) and the lowest in Switzerland (23.2%). In the USA and Switzerland, most salts were taken daily with pasta (salted and boiled), and in Mexico, with tacos (corn or wheat flour tortilla with beef, onions, garlic, spices and tomatoes). The lowest ranking items were cookies and sweet buns, cereal bars and breakfast cereals and crackers.

**Table 3.** Ranking of salt content in cereal products and its percentage share in the daily intake in various countries.

| Country | Ranking of the Content of NaCl in Cereal Products | Percentage of Daily NaCl Intake [%] | References |
|---|---|---|---|
| Latvia | Bread and flour products > breakfast cereals and oatmeal porridge > biscuits, cakes and bread rolls | 15–67 | [72] |
| USA | Pasta > rice > taco and burrito > pizza > savoury snacks > sweet snacks > yeast breads and tortillas > breakfast cereals and bars | 3–21 | [89] |
| Poland | Bread > snacks (breadsticks and crackers) > breakfast cereals | 1.1–23.7 | [39] |
| Switzerland | Pasta and rice > pastries > bread | 16.2–23.2 | [58] |
| Brazil | Bread > rice > pasta > crackers | 2.59–12.38 | [90] |
| Australia | Bread and bread rolls > mixed cereal dishes > pastries > breakfast cereals and bars > savoury biscuits > muffins | 2.0–13.4 | [20] |
| Australia | Bread and rolls > breakfast cereal > mixed dishes with cereals | 2.9–10.9 | [45] |
| Mexico | Tacos > pizza > sweet bakery > savoury bread > breakfast cereal > wheat flour tortillas > crackers > cookies and cereal bars | 2.9–21.8 | [18] |

Despite considerable differences in the eating habits of adults living in various European countries (reflecting regional differences reported in 2014 by the European Commission) [73], the content of salt in the diets of Europeans can be obviously reduced by implementing changes in basic food categories, such as milk/dairies, meat/meat products, grains/cereal products (including bread). Since cereal products are most often consumed and in the largest amounts around the world, decreasing the amount of salt in bread can largely contribute to reducing salt consumption throughout the population. The WHO [98] established global sodium benchmarks for 18 food categories, including bread and bread products. These benchmarks were developed to call for accelerated action from Member States to scale up their efforts to reduce their populations' sodium intake. The benchmarks for bread and bread products are as follows: 475 mg/100 g for scones and soda bread, 330 mg/100 g for yeast-leavened breads with all types of cereal flours, 320 mg/100 g for flat breads (tortillas, wraps, naan, pita) and 310 mg/100 g for sweet rolls with raisins/nuts. Some European countries, as well as certain African and Asian ones [21], have successfully implemented measures to reduce salt content in baked goods [99,100]. This data corroborates the significance of the intersectoral approach to changes in food composition and social education on minimising the amount of salt added to homemade meals [101]. The European Commission [73] recommends a 1.0–1.2% salt content. Recently, most countries reduced the amount of salt added to baked goods, yet this limit is sometimes exceeded. Details are presented in Table 4.

**Table 4.** The average content of NaCl in bread in various countries.

| Country | Average Content of NaCl in Bread [%] | References |
|---|---|---|
| Latvia | 0.8–1.2 | [87] |
| UK | 0.95 | [100] |
| Germany | 1.6 | [101] |
| Ireland | 0.6–1.68 | [102] |
| Poland | 1.64 | [39] |
| Switzerland | 1.0 | [58] |
| Netherlands | 1.19 | [103] |
| Italy | 1.5 | [104] |

## 7. Initiatives to Reduce the Content of Sodium in Food Products and Meals

An excessive intake of NaCl with the diet (>5–6 g/day for adults and >3–6 g/day for children) is observed in most countries of Europe and the world [11]. Results of many years' analyses of the content of Na in food products in various countries testify to the effectiveness of the gradual reduction-oriented campaigns [4].

The WHO promotes reduction of salt as the best strategy aiming to restrain chronic diseases and Member States approved the target of 30% reduction in average intake of salt by the population by 2025 [105]. The Eastern Mediterranean Region has the highest number of countries in the world (>20%) implementing mandatory salt limits in foods [17]. To date, 5% of Member States ($n$ = 9) have implemented at least two mandatory sodium reduction policies and other measures, 22% of Member States ($n$ = 43) have implemented at least one mandatory policy or measure, 33% of the remaining Member States ($n$ = 64) have implemented at least one voluntary policy and other measures to reduce sodium intake, while 29% ($n$ = 56) have made a policy commitment towards sodium reduction [17]. Education at the population level can be more effective in reducing the intake of sodium with the diet than individual interventions [106].

National salt reduction initiatives were multifaceted in approach, characterized by a combination of two or more implementation strategies. Interventions in settings (including interventions targeted at schools and hospitals) were the most common approach. This was followed by food reformulation through engagement with the food industry (established salt targets), consumer education interventions (led by the government, non-government organizations and the food industry), front-of-pack labelling schemes (through warning labels, traffic lights, health messages and percentage daily intake or guideline daily amount) and salt taxation [17].

### *7.1. Changes in Food Products Labelling*

Front-of-pack (FOP) nutrition labelling is an efficient strategy allowing consumers to make conscious and healthier food choices [107]. Countries of the world feature different labelling practices with reference to functional and visual aspects, such as type of expression (discretionary or mandatory) and presence of any guidelines for consumers facilitating label interpretation [108]. In some countries, front-of-pack labelling is mandatory (e.g., in Chile, Sri Lanka, Argentina, Indonesia and Finland), but in most of them it is discretionary (e.g., in France, Australia, New Zealand, China and Malaysia) [17]. Labels facilitating nutritional value interpretation show prints, symbols or warnings referring to general content of nutrients in the product. These include, for example, Chilean style warning labels taking note of the content of salt, saturated fat, sugar and the product's energy value; the Multiple Traffic Light is used in some countries, including the United Kingdom, indicating red (high), amber (medium) or green (low) levels of nutrients (energy value, content of sugar, fat and saturated fatty acids and salt) per serving; and the Health Star Rating used in Australia and New Zealand where the rating from a half to five stars shows if the product is healthy [109,110]. Some labelling schemes (e.g., Guideline Daily Amount in the United Kingdom) convey nutritional content as numbers rather than graphics, symbols or colours, allowing consumers to create their own judgements on healthfulness [111].

On 13 December 2014, Poland put a Regulation of the European Parliament and the Council (EU) No 1169/2011 into effect regarding the provision of food information to consumers. The above-mentioned regulation imposed an obligation—effective as of 13 December 2016—to provide the following information on food packaging: energy value, fat content, saturated fatty acids, carbohydrates, sugars, protein and salt [10,112].

Nutri-Score is a food labelling system implemented in Poland in 2021. Similar Nutri-Scores have been in use for some time in other European countries, including France, Norway, Sweden, the Netherlands, Denmark and Iceland. The European Commission is currently working on making such labelling mandatory. Nutri-Score is a nutrition label using five colours to facilitate assessing whether the product is healthy or not without analysing the lengthy list of ingredients. The scale ranges from the dark green code marked with the letter A to the red code marked with the letter E. Green corresponds to the healthiest products that should be consumed as often as possible. By contrast, E denotes food processed to the highest extent, the consumption of which should be reduced. High-energy products, sugar, saturated fat and salt are negatively evaluated components. In turn, protein, dietary fibre, fruits and vegetables are beneficial ingredients. In our opinion, Nutri-Score should also take note of trans-fatty acids, omega-3 acids, product processing degree and natural additives, such as bioactives and vitamins. The final score is calculated per 100 g or 100 mL of the product, employing a special algorithm that considers the above-mentioned factors and assigns relevant scores. It makes sense but, in some cases, can lead to preferring products consumed in large servings and deprecating those with smaller servings. For example, yoghurt with slightly inferior ingredients and a lower Nutri-Score can be sold in a smaller packaging than its superior counterpart. Therefore, considering typical product servings is a better solution. French scientists developed this system from Santé Publique France to allow consumers to make conscious buying choices [10]. Julia et al. [113] reported that 52% of respondents found Nutri-Score easy to understand compared to other nutrition labelling systems. In addition, 40% claimed that the label helps them choose the right products to buy. The WHO Europe found Nutri-Score to be an important element of the strategy for combating diet-related diseases, which helps consumers make conscious buying choices based on the nutritional value of products. Scientists hope to encourage more people to think about what they put on their plates and incorporate healthier habits in their lives [10]. However, we do notice certain shortcomings of Nutri-Score. For instance, due to energy density and added salt, fatty smoked fish (salmon) is rated lower than certain sweets; dark chocolate (though objectively healthier than milk chocolate) has the same value class (D or E depending on its kind); oatmeal and chocolate cereal are both class A; the system does not distinguish between whole-grain pasta and regular (wheat) pasta or between kinds of rice (brown, white) and groats (coarse, hulled); Nutri-Score reduces the value of high-fat products in two ways (on the one hand on account of their calorific value, and on the other hand on account of fat content, e.g., avocado oil is class D).

In 2022, researchers from the Medical University of Warsaw published a report of their survey [114]. The survey was sent to nutrition and dietetics experts. Only 7% of them agreed that Nutri-Score should be adopted in Poland in its current form. However, the majority of experts (59%) responded that Nutri-Score should be adopted with some modifications. An update of Nutri-Score algorithm is planned to address most of the above-mentioned weaknesses and allow consumers to make real comparisons of foodstuffs [115].

In 2016, under Canada's Healthy Eating Strategy, Health Canada updated its food labelling regulations. The regulations require that the reference sodium intake coverage be added to nutrition tables on food packaging, assuming 1500 mg/day as the reference value for children's food and 2300 mg/day for food meant for the adult population [116]. In turn, Canadian regulations establish 60 mg/100 kcal as the maximum amount of sodium in infant formulas [117]. The Healthy Eating Strategy was a supplement and improvement to Canada's Food Guide that recommends reducing the consumption of processed foods or ready meals with high sodium content. Limitations on food and drink marketing targeted at children and adolescents are still a promising political initiative. In 2022, food nutrition facts labels were enhanced based on consumer opinions. Among other modifications, a note on the percentage content of nutrients (including sodium) in the product was added to help consumers understand how much of the specific nutrient the food contains, indicating that 5% or less is 'little' but 15% or more is 'a lot' [117].

Since 2009, the Codex Committee on Food Labelling in the United Kingdom has approved including sodium or salt in the list of nutrients to be disclosed on food labels. An international work group was also appointed to discuss which of the two terms—sodium or salt—should be preferably used on the label [118]. At present, two types of nutrition labels exist in the United Kingdom. Firstly, there are voluntary traffic light labels that indicate if the content of saturated fat, sugar and salt is low or high. Red light (product high in the nutrient) recommends careful consumption, yellow light (medium content) raises awareness of an increased risk of health problems, and green light (low content) means that the nutrients are safe to health if standard servings are consumed. Another variant of packaging front labels used in the United Kingdom is GDA (Guideline Daily Amount), which provide information on the total count of calories, fat, fatty acids, sugar and salt in the product and what percentage of the recommended daily intake for adults is satisfied by one serving of the product [79]. A comparison of foodstuffs in the United Kingdom in 2006 and 2011 showed a general average reduction of sodium content by 7%. The sodium content was significantly reduced in ready-to-eat meals, dairy products, sauces and spreads. Decreases in these product groups outweighed increases in the salt content of non-alcoholic beverages and processed vegetables [119]. Thus, voluntary reduction of salt encouraged by the Food Standard Agency contributed to decreasing the overall salt level in food available in the United Kingdom.

On the one hand, the use of FOP labelling on products engages consumers, but, on the other hand, may potentially stimulate food processors to reformulate products to meet nutrition criteria so they can avoid carrying negative FOP labels [120]. In 2016, a black stop sign was introduced in Chile as a comprehensive warning programme covering products with exceeded limits for sodium, saturated fat, total sugars and total energy [121]. A comparison of food labels before and after the first year in which the programme was adopted shows that the percentage of products which should have sodium content warning labels decreased, which implies that food processors reformulated products to avoid a black warning label [122].

Certain limitations on changing food labels do exist. In the study conducted by Haghighian Roudsari et al. [123], insufficient knowledge on label interpretation, small size of back-of-pack traffic light labels and absence of substitutes for red light foods were the principal problems faced by consumers. It is also more difficult to interpret labels if the values are given per serving size instead of 100 g. People are not aware of the definition of serving size, and therefore, using this reference would make the label more complicated. Using a per 100 g reference allows comparisons both within and between food categories. Furthermore, evidence from Australia and New Zealand indicates that the slow uptake by only a small proportion of companies illustrates the limits of commercial goodwill in applying front-of-pack labelling systems voluntarily [17].

### *7.2. Health Campaigns*

Bolder actions are still needed to see measurable public health impact. The main WHO goal is to save lives the millions of people. However, the global burden of unhealthy diets constitutes a major public health and development challenge worldwide. In order to increase the benefits for public health, various activities are undertaken, including health campaigns. While such initiatives generate costs, they reduce the availability of unhealthy foods and may result in lower healthcare system costs for chronic diet-related diseases [17]. High-income countries have started to enact public health policies, such as mass media campaigns or limiting salt in processed foods, to reduce the prevalence of hypertension in their populations [124,125]. To date, 96 of 194 Member States associated with the WHO have initiated mass media campaigns focusing on salt intake reduction [17].

The Polish National Food and Nutrition Institute in Warsaw symbolically crosses out the saltshaker on the Pyramid of Healthy Nutrition and Physical Activity and proposes several ways to reduce the intake of NaCl in the diet, such as: limiting the amount of salt added during meal preparation or, if necessary, adding salt at the end of cooking, using fresh or dried herbs instead of salt and choosing products with lower salt content. Special attention is drawn to the use of KCl salt [47].

The British programme Eating Well, Choosing Better, run by the Food Standards Agency, encourages manufacturers to reduce the level of sugar, saturated fat and salt in the food they produce and sell. Salt reduction targets from 2012 were extended in 2017 and finally applied to 76 categories of food. So far, the salt level in many food products has been reduced by as much as 40–50%, and more than 11 million kilograms of salt have been removed from the food. However, the average salt intake in the United Kingdom remains high, amounting to 8.1–8.8 g a day [126].

In 2012, South Korea implemented its National Plan to Reduce Sodium Intake to reduce population Na consumption by 20%, to 3900 mg/day, by 2020. The plan included five key components: a consumer awareness campaign designed to change food consumption behaviours, increased availability of low-sodium foods at schools and worksites, increased availability of low-sodium meals in restaurants, voluntary reformulation of processed foods to lower Na content and development of low-sodium recipes for food prepared at home. It is now known that multicomponent interventions have great potential to reduce population Na intake. The added advantage is that reductions in Na intake were accompanied by reductions in population blood pressure and hypertension prevalence [127]. According to Kweon et al. [128], sodium intake declined significantly over 20 years (4585.6 mg in 1998 and 3255.0 mg in 2018), and notably from 2010. Sodium intake was reduced due to the implementation of the sodium intake reduction policy. The National Plan to Reduce Sodium Intake was a campaign to increase social awareness and optionally reformulate processed foods, including fried pasta, confectionery pastes and products, in order to reduce their sodium content [127].

Alawwa et al. [129] reported that, due to the high intake of sodium by Jordanians, several strategies developed by the WHO to reduce salt intake should be adopted, such as identifying the main sources of sodium in the diet, changing the composition of some food products available on the market, preparing information materials on health to promote the consumers' awareness of salt and informing them of how to read and interpret food labels.

Considering the alarming data from across the world, the WHO [130] presented its recommendations under the Global Action Plan for the Prevention and Control of Non-Communicable Diseases (2013–2020), and according to these recommendations, sodium in the diet should be reduced to less than 2000 mg or 5 g of salt per person and the level of salt/sodium added to food (prepared or processed) should be reduced by 2020, which will decrease the risk of developing hypertension, i.e., the main CVD and renal failure risk factor. However, despite continuing efforts, the latest data implies that salt consumption is twice the limit recommended by the WHO [17]. More coordinated efforts are needed to develop efficient national salt reduction programmes, maintain high-quality monitoring, and implement policies and interventions known to reduce salt intake at the population level effectively. Even a slight decrease in salt intake in a population has a material impact on human health, and many small measures taken together can make a big difference [131].

The feasibility and effectiveness of health campaigns is not normally verified before and after their implementation, and hypertension treatment and control rates are still unsatisfactory [125].

### *7.3. Salt Use Limitations in Food Manufacturing*

Urgent action is required to modify the production and consumption of foods and beverages, including the manufactured food industry. Mandatory maximum limits for sodium in processed foods promote industry-wide reformulation and create a marketplace that restricts the least healthy food options regardless of where people shop or how much they understand and have access to information on labels. The aim is to provide industry with incentives to reformulate and produce healthier products [17].

In 2022, the WHO developed benchmarks for sodium content in 18 food categories and called on food operators to implement them globally [98]. Some of the large food manufacturers have committed to taking steps to achieve those benchmarks, but again, bolder action and engagement from more actors is needed to see measurable public health impact. In total, 34% ($n$ = 65) have implemented policies to reformulate manufactured food to contain less sodium through mandatory (11%), mandatory and voluntary (3%), or voluntary (20%) approaches. Reformulation is most commonly implemented in the WHO Eastern Mediterranean and European regions, and is more common in the higher income group. Bread and bread products are the most targeted food category for sodium reduction, followed by processed meat, poultry, game, fish, ready-made and convenience foods, and savoury snacks [17].

Bread is the main candidate for changing the product's composition (36%), followed by processed meat (28%) and ready meals (23%) [105]. As recommended by the European Commission, the amount of salt used in the production of baked goods should be reduced to 1.0–1.2% per 100 g of flour, and the Member States are required to inform the public about the content of salt in food and the reduction of its levels [73]. Mello et al. [90] report that the content of sodium in baked goods has been recently lowered in Brazil. Analysis of the content of sodium in baked goods sold in Poland in 2017 showed that bread provides 7.59 g of Na per 1 kg [23]. More current data is not available, but the Polish market shows an upward trend in contrast to certain other countries. Research needs to continue to assess the current content of salt in baked goods sold in Poland.

At an individual level, nutritional guidelines for the Brazilian population assume a moderate sodium intake. Moreover, at the population level, the Brazilian Association of Food Industries referred to those guidelines in creating a voluntary agreement that involves more than 70% of the market of sodium-based processed food for specified categories of food: baked goods, pastries, cookies and biscuits, pasta, spreads, breakfast cereals and mayonnaise. Sodium reduction targets in these products improved as sodium levels were gradually reduced in 2011–2017 [132].

Food reformulation is rated as the intervention with the highest priority in terms of effectiveness, equity, sustainability and acceptance by policy-makers [107]. Several previous systematic reviews of food reformulation interventions showed reductions in salt consumption across an entire population [106]. However, structural features, such as voluntary or mandatory nature, can determine the success of food reformulation interventions [133]. Voluntary approaches to food reformulation depend on strong government leadership, extensive advocacy activities, cross-industry collaboration and robust monitoring of salt content in selected products, and most importantly, publishing the results in order to hold the food industry accountable [134].

### *7.4. Taxes on High Salt Content Products*

Only one Member State, Hungary, has had an excise tax since 2011 targeting foods high in sodium through underlying nutrient profile modelling. In Portugal, a proposed tax on salt-rich foods was considered in 2018 but was ultimately not approved by the Parliament. Hungary imposed taxes on salty snacks with salt content > 1 g/100 g and on food seasoning with salt content > 5 g/100 g. This tax amounts to 0.8 €/kg of salt. The tax contributed to reducing salt content in many food products by, in some cases, as much as 85%. The effects of salt taxation included a reduction in the sale and consumption of salty snacks by 26% [135]. The main reason behind the change in consumer behaviour was the increase in prices and raised awareness of the negative impact of salt on health [73].

The possibility of imposing taxes on food of little value, such as high-sodium food, may be promising as it will no longer be readily available or affordable [136]. In turn, this can offset the prices of salt substitutes as the demand for them will increase. Although, as a rule, salt substitutes are about 50% more expensive than ordinary salt, they are still very cheap. Salt substitutes are thus available to most patients and seem a good supplement to blood pressure control medication [134]. With time, the use of substitutes can modify the population's taste preferences and consumption norms. Nevertheless, the content of salt in food reduced by the food industry will most likely reduce the intake of sodium by the population to a higher extent than high-sodium-food taxes [136].

### *7.5. Use of Salt Substitutes*

If the amount of salt in food changes, steps should be taken to maintain product acceptability. Usually, this is performed by altering the chemical profile using salt substitutes or boosters, maximum stimulation of salt receptors by ensuring the quick release of salt from food surface, and decreasing consumer preferences regarding salt. The human salt taste receptors can adapt and become more sensitive to low salt concentrations within only 4–6 weeks; therefore, a small gradual decrease in the sodium content of processed food cannot be detected. This means that foods with lower salt content will taste as salty as highly salted foods before the adjustment. Furthermore, evidence indicates that, once salt intake has been reduced, consumers prefer foods with less salt [107]. For instance, in the United Kingdom, salt content in major brands sold in supermarkets reduced by 20–30% over three years did not affect their sales or consumer preferences [100].

Several countries (including the United Kingdom) have considered replacing table salt with salt substitutes containing less sodium, that is, potassium-based salt replacers (KCl) or other similar equivalents, such as magnesium ($MgCl_2$, $MgSO_2$), as a potential blood-pressure-lowering strategy [137]. Diets higher in sodium and lower in potassium have been considered a leading factor for the development of hypertension. The majority of junk foods and processed and packaged foods have higher sodium contents, and higher sodium and lower potassium dietary intake has become a serious global health challenge. The adverse ratio of both electrolytes is strongly linked to blood pressure and the dietary Na:K ratio is an independent risk factor for metabolic syndrome. Furthermore, modify ratios, including lower Na intakes and higher K intakes (e.g., replacing NaCl with KCl), was suggested as a strategy to prevent metabolic disorders, including hypertension [138]. The meta-analysis of randomised controlled studies showed that salt substitutes low in sodium compared with common salt reduced mean systolic blood pressure by 7.81 mmHg and diastolic blood pressure by 3.96 mmHg. The effects in hypertensive, normotensive and mixed populations were similar [139]. Using salt substitutes (65% NaCl, 25% KCl and 10% $MgSO_4$) was found to be a feasible and effective dietary approach to reducing salt intake in the population of China, which can significantly help restrain cerebral stroke prevalence among the Chinese people living in rural areas by up to one million cases every year [134]. In the above-mentioned study, systolic pressure in hypertensives was reduced within 12 months by 4.0–5.4 mmHg; however, diastolic pressure did not change.

Gusmão et al. [22] examined the quality and flavour of baked goods in which KCl partially substituted NaCl with satisfactory results with regard to both rheological aspects and flavour evaluated by consumers. A bread dough recipe containing 1% NaCl and 0.5% KCl reduces the content of Na in the product by 56% without significantly compromising the quality of bread. In turn, Bassett et al. [140] partially substituted (50, 70 and 80%) NaCl by a mixture of $CaCl_2$ and $CaCO_3$ (1:1 ratio). Those authors found that bread containing 50% of NaCl was not different in organoleptic properties from bread that contained only table salt. However, there is a risk that a reduction in the content of NaCl for KCl (>30%) can lead to an increase in the relative content of Mg and K, which can lead to a metallic taste and bitterness of bread that are not acceptable to consumers [141].

In studies exploring taste acceptability of six different potassium-enriched salt substitutes, more than 80% of individuals did not differentiate between regular salt and potassium-enriched salt substitutes containing less than 30% KCl [142]. The risks of potassium-enriched salt substitutes include a possible increased risk of hyperkalaemia and its principal adverse consequences: arrhythmias and sudden cardiac death, especially in people with conditions that impair potassium excretion, such as chronic kidney disease [143]. However, there is not enough evidence regarding the effects of potassium-enriched salt on serum potassium levels and the occurrence of hyperkalaemia in people with chronic kidney disease and others at risk for hyperkalaemia [144]. Five studies from meta-analysis conducted by Tsai et al. [145] provided the data of follow-up serum potassium level. Using salt substitute increased the serum potassium by 1 mmol/L, but it did not achieve significant elevation in serum potassium level. This is confirmed by other studies. In a study by Yuan et al. [146] noted clear benefits of a salt substitute (KCl) compared to NaCl in lowering blood pressure as well as protecting against cardiovascular events among elderly people living in nursing homes in China. These benefits were accompanied by an increase in blood chemistry hyperkalaemia, but there was no evidence of adverse clinical outcomes. In turn, in the study by Yu et al. [147], conducted among Indian hypertensive patients and where NaCl was also replaced with KCl, no adverse clinical events, including hyperkalaemia, were observed.

Kremer et al. [148] tested the palatability of bread in which soy sauce was the only source of Na, apart from Na naturally occurring in grains, with no additions of Na in forms other than salt, for example, monosodium glutamate. As a result, the salt level in bread was reduced by 38.9%. According to consumers, such bread was no less attractive than the standard one. The quality and acceptability to consumers were also maintained for other food products (such as cheese or processed meat products) if the content of salt was reduced gradually [149–152].

Approaches to using potassium-enriched salt substitutes as the main alternative may vary from country to country, depending on food preferences and the source of sodium in the population's diet. In countries such as the United States, where 70% of the total sodium intake derives from commercially processed food and meals consumed in restaurants, food reformulation can be a particularly effective sodium reduction strategy [153]. By contrast, replacing common salt added to meals cooked at home can be more effective in countries such as China, where even three-quarters of sodium intake derives from salt added to cooked meals [154].

Another way to increase the perceived saltiness of food is salt flavour enhancers. For instance, organic acids such as lactic, citric and acetic acids and some amino acids (arginine, aspartic acid, lysine and glutamate) enhance salty taste [155,156]. Moreover, monosodium glutamate and yeast products can be used for enhancing salty taste, often in combination with KCl [156].

### *7.6. Avoiding Adding Salt for Cooking*

Although pasta contains less than 200 mg Na per 100 g and thus is not considered a high-sodium food itself, it is often served with sauces, which can dramatically increase its Na contents upon its consumption [65]. It is noteworthy that significant and varying Na content results from salt added during preparation. In our study, our team noticed that salt added to water while cooking pasta increased the content of Na nearly five times compared to pasta cooked in unsalted water. In turn, using water without salt reduced the content of Na in the cooked pasta by 48% compared to its content in pasta cooked in water with 3.17 g of salt and by 99% compared to its content in pasta cooked in water with 6.34 g of salt [157]. According to Bianchi et al. [158], due to increasing the content of Na in water by adding salt, Na from the solution penetrates the product, thereby reducing the content of other minerals, while cooking in unsalted water causes Na to penetrate from the product into the water. The degree of penetration of minerals from pasta into the water and vice versa during cooking depends on the content of Na in water. Reducing (or eliminating) the amount of salt added when cooking pasta is a quantitative and straightforward way to reduce dietary Na. It could also be communicated that rinsing after cooking could reduce by one-third the Na content of pasta cooked in salted water, but other minerals, such as Zn, Mn, K, Cu, Fe, Ca and Mg, are flushed at the same time [157,158]. Only additions to pasta, such as sauces, should be seasoned, whilst one should reduce the amount of salt when seasoning, and instead of salt, use herbs and natural spices for flavour [157]. Because Na in the form of table salt is very soluble in water and easily diffused, the recommendation not to add salt to the water when cooking may also apply to other foodstuffs, such as eggs, rice, groats, vegetables, and legumes [54,157].

In addition, effective ways of reducing the amount of salt in the diet are reducing product serving size, using low-sodium products, and controlling the use of intermediate goods in households. Figure 3 presents selected strategies to reduce Na intake from foods.

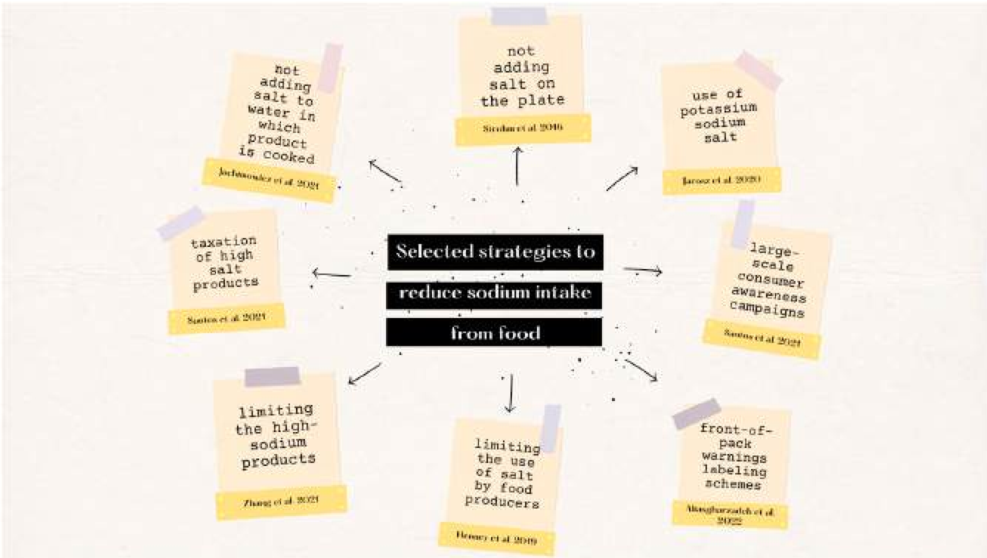


**Figure 3.** Selected strategies to reduce sodium intake from foods [4,47,65,107,135,157,159].

## 8. Perspectives and Conclusions

In 2016, the FDA acted on the IOM's recommendation by proposing federal recommendations for phased reductions in Na content for about 150 food categories. Some food companies, such as Danone North America, Mars, Nestlé, PepsiCo and Unilever, agreed that reducing Na levels can be important for public health and that food companies should do more to reduce Na in their products [159,160]. International authorities on human health support the idea that reducing salt content in food is a viable strategy for improving public health status. Food industry sectors are engaged in limiting salt intake despite the fact that changing product composition can entail additional costs of product development. Therefore, businesses from the food sector should be encouraged to put healthy diet components on the market. In the first place, this can be performed through selective taxation and subsidies, marketing control and regulations on food quality, and—from a longer perspective—consumer wishes to combine healthier food with a continuous pursuit of comfort [161]. Furthermore, through their Live-Well programme, the USA attempts to ensure that participating restaurants offer healthy food to children and adolescents, encouraging them to eat more fruits, non-starchy vegetables and wholegrain products, and to limit the consumption of added sugar and sodium [162]. The content of NaCl in the diet should be reduced not only by food producers but also by changing the population's eating habits and nutrition education [163]. However, collaboration from all parties is necessary to reduce salt consumption efficiently; it is not enough to reduce salt content in food products. Consumers should be encouraged to buy low-salt products and limit salt intake at their own discretion [164]. Figure 4 presents the effects of excessive consumption of salt and the benefits of its reduced intake.

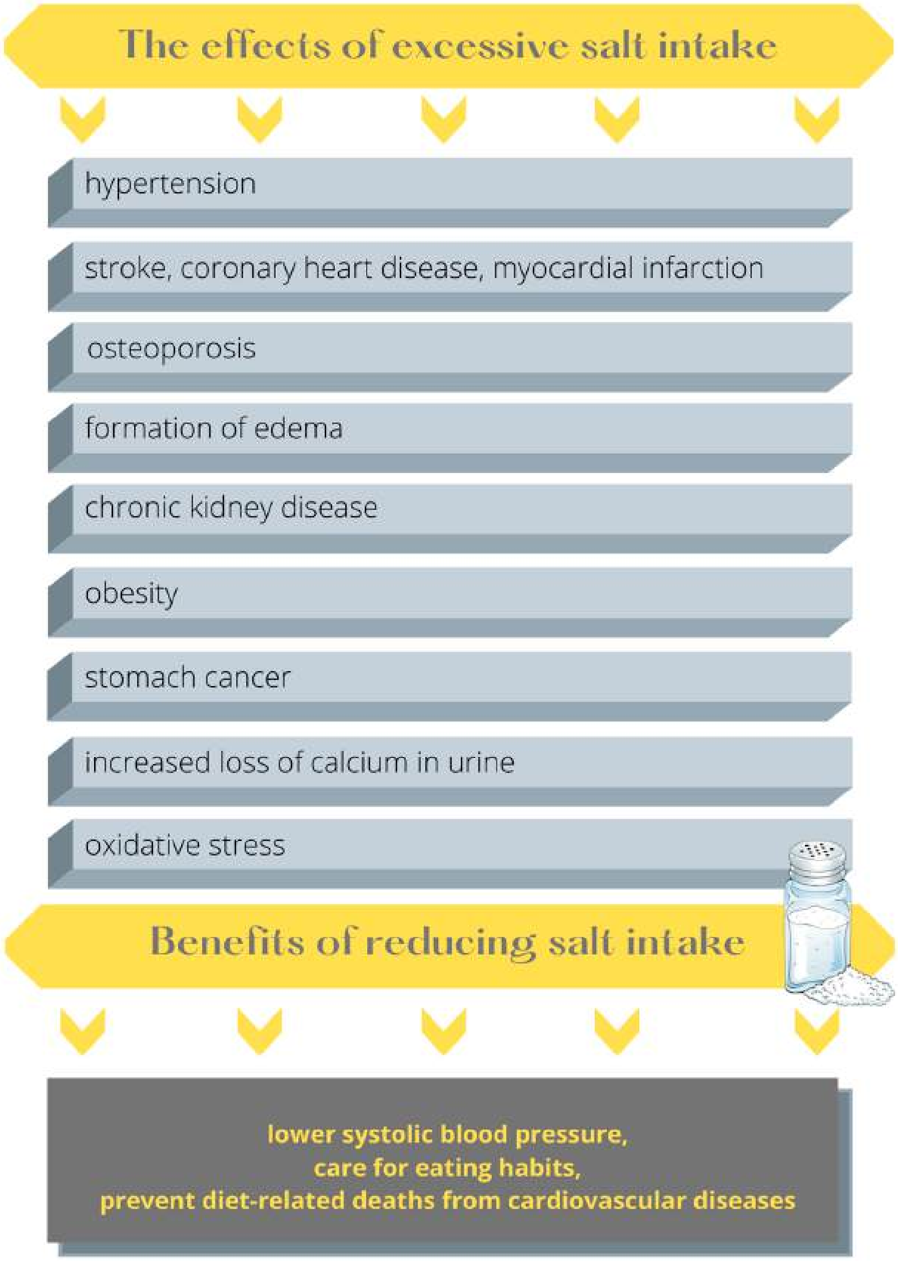


**Figure 4.** Effects of excessive salt intake and benefits of reduced salt intake.

A review of studies revealed numerous national and international salt reduction strategies worldwide. Many countries (in Europe and globally) developed strategies to reduce salt intake and strive to reduce salt consumption using behavioural and structural preventive measures gradually. However, despite their numbers growing, none of these countries has achieved the target of 30% relative reduction of salt intake by 2025 [135]. To date, not every Member State has implemented rapid strategies of government-led and comprehensive mandatory sodium reduction policies and other measures. This may be due to insufficient awareness of the governments about the significant impact of reducing dietary sodium on human health and life. In our opinion, the WHO report from 2023 [17] will encourage countries to fulfil obligations and contribute to saving millions of human lives. The WHO proposes that, if all countries accelerate policy adoption to ensure at least two mandatory interventions and implementation of best practices, it is possible to dramatically reduce salt intake. Therefore, whether to extend the target to 2030 is being considered. The analyses by Hendriksen et al. [44] show that, compared to other

European countries, Poland will derive more benefits from reducing salt intake; a 13.5% reduction in cerebral stroke occurrence is expected, while in Finland, this number will be 6.4% only. Institutions in charge of these measures must accelerate their efforts, regularly monitor and evaluate their strategies, and share their findings of efficient measures with other countries to ensure that they will achieve the global target together. The mission to reduce salt, both hidden in food products and added when preparing meals, will allow for the improvement of eating habits in the youngest generation and prevent deaths from diet-related cardiovascular diseases. Furthermore, it will contribute to decreasing the consumption of processed foods (accounting for about 75% of daily intake of salt in many high-income countries).

It is necessary to develop and effectively promote relevant strategies and implement them, e.g., by means of media campaigns, as well as to adjust legislation regarding acceptable levels of Na in the most popular products (i.e., most frequently consumed ones). In turn, the fact that information about the content of Na is often missing from food labels is an inconvenience to consumers [23]. The findings of Korošec and Pravst [97] were similar, as only 1% of labels on more than 5000 analysed foodstuffs in Slovenia displayed such information. A need also exists to educate society at the national level about recommended sodium intake with the diet and, most importantly, about sources of sodium in the diet, to raise the population's interest and motivate the commitment to reduce salt. Individual consumers should be encouraged to use as little salt as possible in preparing their meals (behavioural prevention) and avoid adding salt on the plate [4]. Instructing society not to add salt in cooking is also essential, along with the controlled use of intermediate products in households.

To reduce salt intake throughout the population, processed food, such as cereal products, meat, cold meats and cheeses, should contain less salt. In view of food technology, the most important and the easiest change to make is reduce the content of salt in baked goods and other cereal products. A reduction in the salt content from 1.2% to 0.6% or even 0.3% had no significant effect on the rheological and physical properties of wheat bread dough. This implies that salt content reduced by half does not significantly reduce the flexibility of bread dough [22]. The biggest opportunity for change in the near future is provided by a moderate reduction of salt content in baked goods, primarily through the partial use of salt substitutes. Further studies on efficient methods of reducing sodium content by changing the ingredients of food products and processing methods are indispensable to facing the challenges of safe food production.

There is the risk of a discrepancy between salt intake calculated based on nutrition interviews or surveys and the actual supply based on 24-h excretion of sodium with urine [105]. However, more reliable studies based on 24-h excretion of sodium with urine are not readily available in daily medical practice. Therefore, it seems that hypertensiologists need to be supported by nutritionists. Considering that the choice of adequate food products and skilful replacement of salt with substitutes is a particularly important issue for reducing salt intake, efforts should be taken to increase the involvement of this professional group in educating patients.

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Article

# Pasta as a Source of Minerals in the Diets of Poles; Effect of Culinary Processing of Pasta on the Content of Minerals

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**Abstract:** Pasta is a product that requires culinary processing which can affect the content of minerals in the finished product. The study aimed to examine how cooking pasta (1) in salted water (1 teaspoon—16 g of salt per 1 litre of water) or unsalted water and (2) rinsing cooked pasta with running water affects the content of minerals. Thirty-five samples of six types of pasta were analysed. The content of minerals was determined using the ICP-OES method. Retention of minerals in the cooked pasta was calculated. Taking the culinary treatment into account, the intake of minerals with pasta was assessed for children, adolescents, and adults, and the values were compared with the recommendations for the population of Poland. The analysed culinary factors had a statistically significant influence on the content of minerals. Adding salt to water when cooking pasta significantly increased the content of Na in the product, which in turn was negatively correlated with the content of other minerals. When pasta was cooked in unsalted water, it contained less Na and more other minerals than pasta cooked in salted water. Rinsing of pasta reduced the content of all minerals. Pasta is an important source of Mg, Cu, and Mn in the diet of Poles. These ingredients are particularly important to ensure correct development and functioning of the human body. The best method of culinary treatment of pasta is cooking in unsalted water without rinsing.

**Keywords:** pasta; cereal products; minerals; culinary processing; food technology; salt; sodium intake; rinsing; minerals retention; nutrition

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## 1. Introduction

Cereal products are the basic food for people all over the world. In 2019, the average monthly consumption of cereal products in Poland amounted to 4.23 kg, where nearly 10% was pasta [1]. Due to their intake volume, cereals are the primary source of minerals in the human diet. Our previously published studies showed that in the population of Poland, cereals cover the requirement of an adult person for K and Mg in ca. 10–15%, Na in nearly 49%, Cu and Mn in more than 55%, with Fe and Zn in ca. 20–30% [2–4]. The most often consumed product is bread, and pasta comes second [1].

Pasta is common in the diets of both Poles and inhabitants of other countries. Due to its neutral taste, it can be served with meat dishes and added to salads and desserts [5,6]. Consumers on the Polish market are offered a wide range of pasta. It differs in shape, dimensions, and ingredients. The basic raw materials for making pasta are semolina and/or pasta flour and water [7]. According to Statistical Yearbooks, the average monthly consumption of pasta per capita in one household in 2019 was 0.4 kg [1]. This is more than the consumption of groats (0.10 kg) and rice (0.15 kg), but less than bread (2.98 kg). Pasta is a source of fibre, carbohydrates, protein, vitamins, and macro- and microelements. The nutritional value of pasta is enriched with various additives: eggs, protein concentrates, milk, yeasts, vegetables, algae, and soybean meal.

The diet of Poles is deficient in most minerals but contains excessive amounts of Na [2–4]. A similar relationship can also be observed in other countries [8–10]. Due to the consumption volume, pasta can be an important source of deficit minerals in the diet. However, the most controversial element is Na, the consumption of which should be reduced. Sodium is necessary for living because it regulates the water and electrolyte management, maintains acid and alkaline balance, and ensures correct transmission of nerve impulses and correct functioning of muscle cells [11]. Large amounts of sodium can have serious consequences to health, including an increased risk of hypertension and cardiovascular diseases [12]. The predominant sources of sodium in a diet are processed foods and salt added to meals [13,14]. The content of sodium in meals increases when salt is added in the course of processing and cooking [15]. The content of salt in packed dry pasta is insignificant (<0.01 g/100 g), but when it is added while cooking, its level may significantly increase. The NHANES study in the United States showed that 11% of sodium comes from salt added to meals [16]. Pasta is a product salted during thermal processing. It is one of the top 12 foodstuffs contributing to excessive consumption of sodium [17]. In the NHANES study, 40% of respondents indicated that they very often used salt in cooking. In addition, the authors of the study found that pasta is one of the five most popular dishes to which salt is added [16]. The producers of pasta available in Poland recommend cooking pasta in water with salt added; the packaging gives imprecise information that water should be salted "to taste".

The parameters recommended for cooking dry pasta differ depending on the producers' indications on packaging and the habits of consumers. The end properties of pasta can be affected by the water-to-pasta ratio, cooking time, cooking, rinsing of the cooked pasta, amount of salt added, and other factors which can differ between the recommended and customary practices [18]. Determining the effect of various cooking parameters would make it possible to estimate the content of sodium and minerals in cooked pasta consumed by a given population, which—in turn—could be directly reflected in recommendations for cooking pasta. Therefore, this work aimed to examine the effects of cooking pasta in salted and unsalted water on the content of macroelements (Na, K, Ca, Mg) and microelements (Zn, Cu, Fe, Mn). In Poland, after cooking, pasta is customarily rinsed with running water to prevent it from sticking together. Therefore, in addition, the effects of rinsing pasta on the content of minerals in the product was examined. This paper is part of a project aiming to estimate the intake of minerals (both toxic and essential) in the Polish population.

## 2. Materials and Methods

### *2.1. Study Material*

Thirty-five samples of pasta of different types and with different ingredients were analysed (Table 1 and Table S1). In none of the products did the producer declare added salt. The products were purchased in August 2019 in grocery stores in Lublin (eastern Poland). All the products were before their expiry date, and 100 g of pasta was weighed from each sample (with the accuracy of 1 decimal place). It was cooked *al dente* in water (100 g of pasta per 1 L of drinking water) with or without table salt (1 flat tablespoon of salt per 1 L of drinking water, which corresponds to ca. 16 g of salt and 6 g of Na), according to the scheme:

NaCl + NR—cooked with salt and not rinsed;
NaCl + R—cooked with salt and rinsed;
NR—cooked without salt and not rinsed;
R—cooked without salt and rinsed.

**Table 1.** Characteristics of analysed products.

| Pasta Type | Number of Samples | Cooking Time, min. (al dente) | Salt Amount in Raw Product, g per kg [1] | Weight of Pasta before Cooking, g | Weight of Pasta after Cooking, g |
|---|---|---|---|---|---|
| Penne | 7 | 7–13 | 0–0.3 | 100 | 294–320 |
| Ditalini | 5 | 5–12 | 0–0.05 | 100 | 290–311 |
| Gigli | 5 | 5–8 | 0–0.5 | 100 | 250–274 |
| Creste | 4 | 5–12 | 0–0.07 | 100 | 300–314 |
| Fusilli | 7 | 4–9 | 0–0.5 | 100 | 313–321 |
| Filini | 7 | 3–8 | 0–0.09 | 100 | 251–271 |

[1] Values declared by producer.

The cooking time was consistent with the recommendations of the pasta producers (Table 1 and Table S1). After cooking, the pasta was strained in a plastic strainer. Next, about half of each pasta sample was rinsed with cold running water for 10 s. The cooked rinsed and non-rinsed pasta was weighed again after two minutes. The prepared pasta was placed in a drier at a temp. of 65 °C for 24 h. Afterwards, it was ground in an electric grinder fitted with plastic cutters. The ground samples were put one by one in separate, tightly closed plastic containers that were stored for one day until further chemical analyses at room temperature.

### 2.2. Chemical Analyses

After manual mixing of material from each sample, 3 g from an averaged collective sample were weighed in three replications. The control sample and the study sample were prepared in an identical manner. They were mineralised in a muffle furnace (temp. 550 °C, time 12 h, antioxidant—ydrogen peroxide), as described elsewhere [19]. The ash obtained as a result of mineralisation was dissolved in 10 mL of 1M $HNO_3$ [20]. The content of Na, K, Ca, Mg, Zn, Cu, Fe, and Mn was determined by means of ICP-OES (Inductively Coupled Plasma—Optical Emission Spectrometers) using a 720-ES spectrometer (Varian, Palo Alto, CA, USA). ICP-OES operating conditions: RF generator power—1.2 kW; plasma gas flow rate—15.0 $dm^3$ $min^{-1}$; auxiliary gas flow rate—2.25 $dm^3$ $min^{-1}$; nebulizer gas flow rate—0.70 $dm^3$ $min^{-1}$; sample flow rate—0.1 mL $min^{-1}$; replications—4; read time—15 s; peristaltic pump rotation—12 rpm. Determination parameters:

Na: wave length 589.592 nm, LOD (limit of detection) 0.25 mg $kg^{-1}$, LOQ (limit of quantification) 0.39 mg $kg^{-1}$;
K: wave length 769.897 nm, LOD 1.04 mg $kg^{-1}$, LOQ 1.27 mg $kg^{-1}$;
Ca: wave length 422.673 nm, LOD 0.03 mg $kg^{-1}$, LOQ 0.05 mg $kg^{-1}$;
Mg: wave length 280.270 nm, LOD 0.03 mg $kg^{-1}$, LOQ 0.08 mg $kg^{-1}$;
Zn: wave length 202.548 nm, LOD 0.06 mg $kg^{-1}$, LOQ 0.09 mg $kg^{-1}$;
Cu: wave length 213.598 nm, LOD 0.03 mg $kg^{-1}$, LOQ 0.06 mg $kg^{-1}$;
Fe: wave length 238.204 nm, LOD 0.03 mg $kg^{-1}$, LOQ 0.05 mg $kg^{-1}$;
Mn: wave length 259.372 nm, LOD 0.10 mg $kg^{-1}$, LOQ 0.23 mg $kg^{-1}$.

The limits of detection (LOD) were calculated using the formula CL = 3 Sb/m [21], where "Sb" is the standard deviation of six replicate blank measurements and "m" is the slope value in the calibration curve.

In order to draw the calibration curve, LCG standards were used for the preparation of mineral solutions with concentrations of 1, 2, 4, and 8 µg per 1 L. The correctness of results was validated by means of the 1M nitric acid ($HNO_3$) and two reference samples: LGC 7173 Poultry Feed and NCS ZC 73,009 Wheat. The rate of recovery of the analysed minerals ranged from 94 to 107% (Table 2). All the analyses were performed in three replications.

**Table 2.** Data of triplicate certified reference materials analysis.

| | Na | K | Ca | Mg | Zn | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|
| Certified reference material | LGC-7173 | LGC-7173 | LGC-7173 | LGC-7173 | LGC-7173 | LGC-7173 | LGC-7173 | LGC-7173 |
| Certified, mg kg$^{-1}$ | 1180 | 7480 | 17800 | 2037 | 78.00 | 14.00 | 148.0 | 90.00 |
| Observed, mg kg$^{-1}$ | 1263 | 7496 | 17523 | 2049 | 81.46 | 13.78 | 139.2 | 87.15 |
| Recovery rate,% | 107 | 100 | 98 | 101 | 104 | 98 | 94 | 97 |
| Certified reference material | NCS ZC 73009 | NCS ZC 73009 | NCS ZC 73009 | NCS ZC 73009 | NCS ZC 73009 | NCS ZC 73009 | NCS ZC 73009 | NCS ZC 73009 |
| Certified, mg kg$^{-1}$ | 17.00 | 1400 | 340.0 | 450.0 | 11.60 | 2.710 | 18.50 | 5.400 |
| Observed, mg kg$^{-1}$ | 15.91 | 1389 | 327.2 | 455.7 | 11.51 | 2.715 | 18.65 | 5.287 |
| Recovery rate,% | 94 | 99 | 96 | 101 | 99 | 100 | 101 | 98 |

### *2.3. Reagents and Reference Materials*

The solutions were prepared using deionized water (deionizer Hydrolab, Gdańsk, Poland) and ultra-pure chemical reagents. Hydrogen peroxide (30% pure) and nitric acid (65% ultra-pure) were purchased from POCH S.A. (Lublin, Poland). The standard solutions of Ultra Scientific minerals (1000 mg L-1, 99.99% purity) was purchased from LGC Standards Sp. z o.o. (Kiełpin, Poland). The certified reference material (CRM) was used to check the quality:

(1) LGC 7173 Poultry feed (LGC Standards GmbH, Wesel, Germany) contained 1180 mg Na, 7480 mg K, 17,800 mg Ca, 2037 mg Mg, 78 mg Zn, 14 mg Cu, 148 mg Fe and 90 mg Mn per 1 kg;
(2) NCS ZC 73,009 Wheat (National Institute of Standard and Technology, Gaithersburg, MD, USA) contained 17.0 mg Na, 1400 mg K, 340 mg Ca, 450 mg Mg, 11.6 mg Zn, 2.71 mg Cu, 18.5 mg Fe and 5.4 mg Mn per 1 kg.

### *2.4. Calculations and Statistical Analysis*

The rate (%) of retention of minerals was calculated from the formula [22,23]:

$$\text{Retention } (\%) = \frac{\text{mineral content (g) in cooked pasta} \times \text{weight (g) of pasta after cooking}}{\text{mineral content (g) in raw pasta} \times \text{weight (g) of pasta before cooking}} \times 100$$

Based on the mean content of Na, K, Ca, Mg, Zn, Cu, Fe, and Mn in cooked pasta, the content of minerals was calculated per 1 serving of pasta, assuming that the serving is 140 g for adults [24], 50 g for children aged 1–3 [25], 60 g for children aged 4–6 [26], 100 g for children aged 7–12 [27], 125 g for children aged 13–15 [28], and 135 g for adolescents aged 16–18 [28]. The mean share of pasta in the reference daily intake was calculated from the formula:

$$\text{Share in reference daily intake} = \frac{\text{Daily dietary intake} \times 100}{\text{Reference daily intake}}$$

where:

$$\text{Daily dietary intake} = \text{Daily portion size} \times \text{average content of minerals in pasta.}$$

The intake of minerals with pasta was compared against Polish RDA—Recommended Dietary Allowances (Ca, Mg, Cu, Fe, Zn) or AI—Adequate Intake (Na, K, Mn) [29]. The RDA and AI values for minerals according to Polish norms are presented in Table S2.

The calculations were made by using Statistica 13.1 software. Mean values were calculated based on three replications per sample. Statistically significant differences ($p < 0.05$) were computed by single-factor analysis of variance (ANOVA), using Duncan's test. Correlations between the minerals evaluated were obtained using Pearson's correlation coefficient (r).

## 3. Results

### 3.1. How the Type of Culinary Treatment Affects the Content of Minerals in Pasta

A statistically significant influence of salt added to water, rinsing the cooked pasta with running water and the type of pasta on the content of minerals was found. Tables S3–S6 contain detailed information.

In NaCl + NR pasta, a strong positive correlation was noted between the content of Mn and K (r = 0.827). On the other hand, NaCl + R pasta showed a strong positive correlation between the content of Zn and the content of K and Mg (r > 0.9), and a strong negative correlation between the content of Mg and Fe (r = −0.882). The relationship between the content of the analysed minerals can be presented as Mg > K > Na > Ca > Mn > Fe > Zn > Cu for NaCl + NR and Mg > K > Na > Ca > Fe > Mn > Cu > Zn for NaCl + R. In NaCl + NR, the retention of Na was, on average, 780%, and in NaCl + R pasta, ca. 300% (Table 3). In NaCl + NR pasta, the retention of K was 254%, and that of Zn, ca. 70%, whilst retention of other analysed minerals ranged from 116 to 163%. In NaCl + R pasta, the retention of K was ca. 190%, Fe—132%, and Zn—32%. The retention of Ca, Mg, Cu, and Mn was close to 100%. Pasta cooked in unsalted water (NR, R) contained less ($p < 0.05$) minerals than raw pasta.

**Table 3.** The retention of Na, K, Ca, Mg, Zn, Cu, Fe, and Mn in products cooked with salt or without salt, and rinsed or not rinsed, % (percentage of mineral retention) *.

| | Cooking Parameters | | | | Influence of | |
|---|---|---|---|---|---|---|
| | NaCl + NR | NaCl + R | NR | R | Salt Addition | Rinsing after Cooking |
| | | | | | ANOVA $p$ Values | |
| Na | $780 \pm 129^{d}$ | $308 \pm 293^{c}$ | $118 \pm 77^{a}$ | $269 \pm 110^{b}$ | 0.002 | 0.001 |
| K | $254 \pm 90^{b}$ | $187 \pm 41^{a}$ | $341 \pm 84^{d}$ | $293 \pm 71^{c}$ | 0.018 | 0.018 |
| Ca | $116 \pm 85^{c}$ | $90 \pm 82^{a}$ | $148 \pm 44^{d}$ | $107 \pm 40^{b}$ | 0.004 | 0.002 |
| Mg | $134 \pm 49^{b}$ | $100 \pm 43^{a}$ | $231 \pm 80^{d}$ | $177 \pm 58^{c}$ | <0.001 | 0.004 |
| Zn | $67 \pm 29^{b}$ | $32 \pm 13^{a}$ | $160 \pm 68^{d}$ | $114 \pm 35^{c}$ | <0.001 | 0.012 |
| Cu | $121 \pm 66^{b}$ | $91 \pm 55^{a}$ | $178 \pm 62^{d}$ | $148 \pm 63^{c}$ | 0.003 | 0.010 |
| Fe | $163 \pm 28^{b}$ | $132 \pm 22^{a}$ | $218 \pm 51^{d}$ | $180 \pm 42^{c}$ | 0.021 | 0.003 |
| Mn | $163 \pm 53^{b}$ | $92 \pm 48^{a}$ | $222 \pm 33^{d}$ | $186 \pm 37^{c}$ | 0.011 | 0.028 |

* Average values for samples, each in 3 replications; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; $^{a,b,c,d}$—values with different superscripts in the same rows differ at $p < 0.05$ by Duncan's test.

The relationship between the content of analysed minerals can be presented as Mg > K > Ca > Na > Mn > Fe > Zn > Cu for NR pasta and Mg > K > Ca > Na > Mn > Fe > Zn > Cu for R pasta. Retention of minerals is presented in Table 3.

At the same time, some general trends in the content of respective minerals can be observed depending on the type of culinary treatment. Irrespective of the type of pasta, cooking in salted water (NaCl + NR, NaCl + R) increased ($p < 0.05$) the content of Na (Figure 1a) and decreased ($p < 0.05$) the content of all other minerals in comparison to their level in raw pasta (Figure 1b–d; Figure 2a–d). In turn, pasta cooked in unsalted water (NR, R) contained less ($p < 0.05$) analysed minerals (except K) than raw pasta, irrespective of its type (Figures 1 and 2). Furthermore, cooking pasta in unsalted water (NR, R) led to a decreased ($p < 0.05$) content of Na and an increased level ($p < 0.05$) of other minerals than in pasta cooked in salted water (NaCl + NR, NaCl + R).

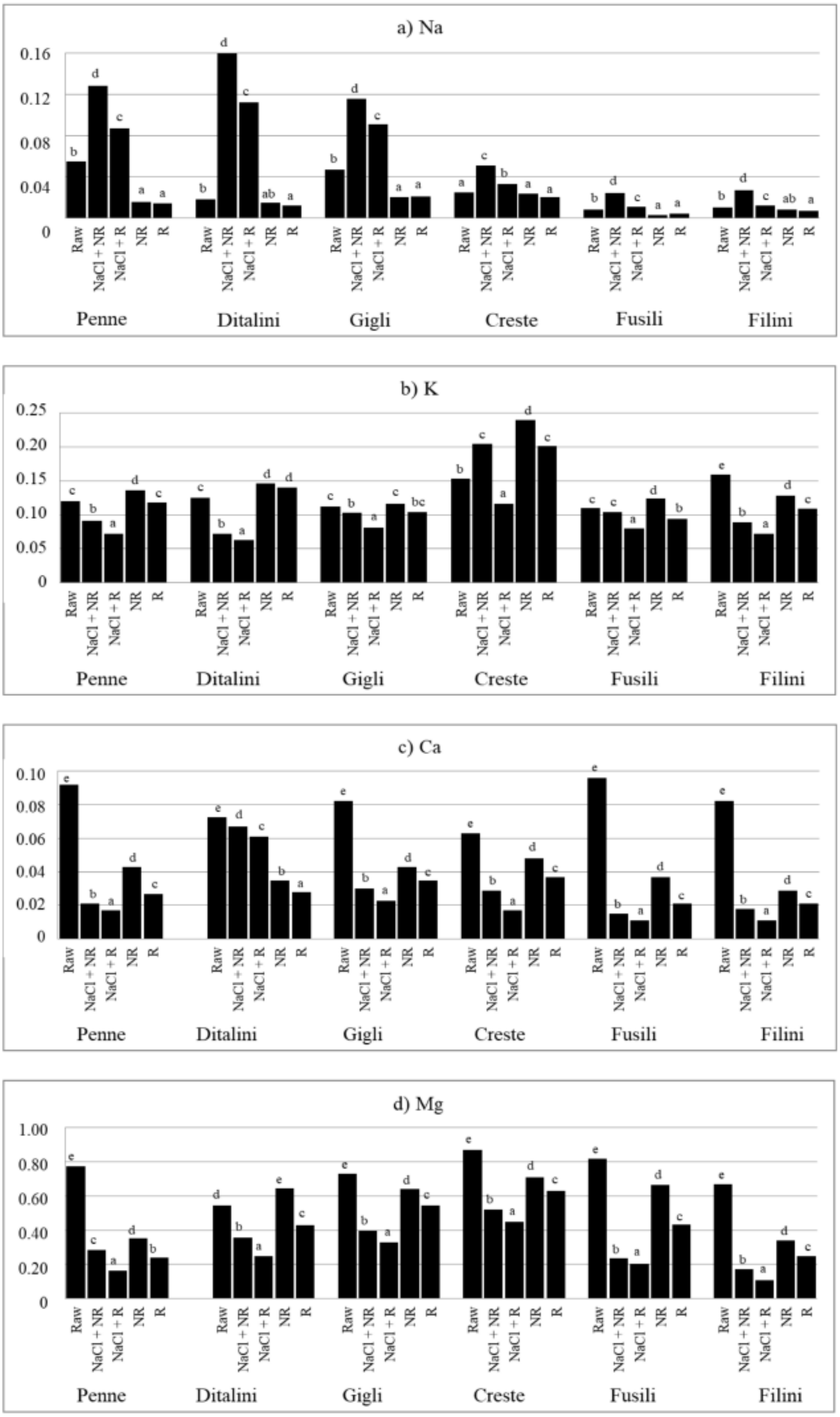


**Figure 1.** The content of: (**a**) Na; (**b**) K; (**c**) Ca; (**d**) Mg in pasta, g $kg^{-1}$ fresh weight. Raw—raw pasta; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; $^{a,b,c,d,e}$—values with different superscripts differ at $p < 0.05$ by Duncan's test.

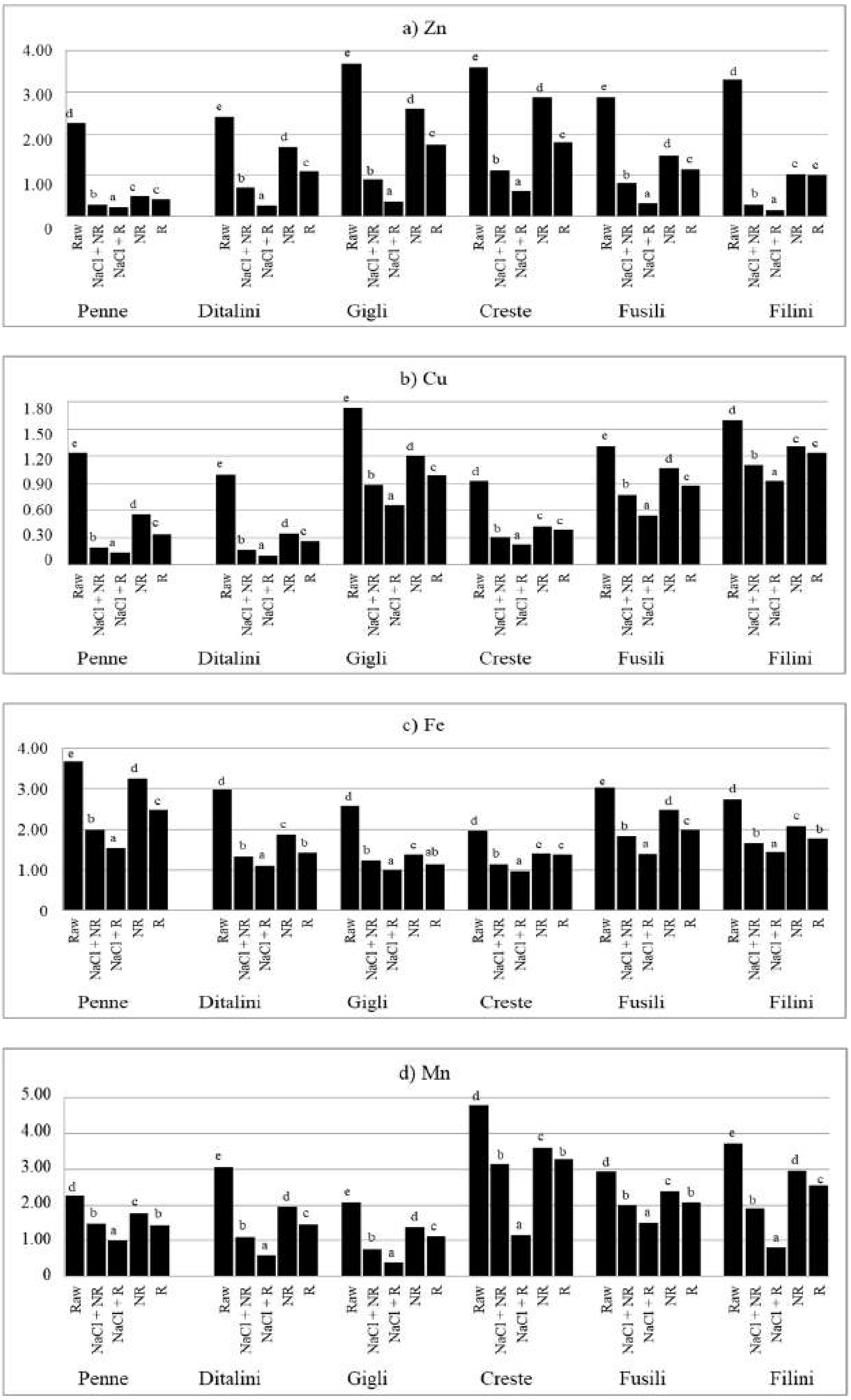


**Figure 2.** The content of: (**a**) Zn; (**b**) Cu; (**c**) Fe; (**d**) Mn in pasta, mg $kg^{-1}$ fresh weight. Raw—raw pasta; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; $^{a,b,c,d,e}$—values with different superscripts differ at $p < 0.05$ by Duncan's test.

Rinsing pasta cooked in salted water (NaCl + R) decreased the content of Zn and Mn by about 50%, and that of other minerals by 20–30% compared to NaCl + NR (Table 4). Rinsing pasta cooked in unsalted water (R) decreased the content of Na by ca. 8%, the content of K, Cu, Fe and Mn by 14–18%, and that of Ca, Mg and Zn by 25–29% in comparison to non-rinsed pasta (NR). Salt added to water while cooking pasta increased the content of Na nearly 3.5 times for rinsed pasta and nearly 5 times for non-rinsed pasta compared to pasta cooked in unsalted water. Rinsing of pasta cooked in salted water (NaCl + R) led to a decrease in the content of Zn by more than 70%, of Mn by more than 50%, of K, Mg and Cu by ca. 40%, and of Fe and Cu by less than 30% as compared to R pasta. On the other hand, the NaCl + NR pattern decreased the content of Zn by ca. 60%, of Mg by more than 40% and that of other elements by a maximum of 30% compared to NR pasta.

**Table 4.** Comparison of the mean content of Na, K, Ca, Mg, Zn, Cu, Fe, and Mn in products cooked with or without salt, and rinsed or not rinsed, %.

| | Na | K | Ca | Mg | Zn | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|
| R vs. NaCl + R [1] | 344 | −36.8 | −17.4 | −40.7 | −73.0 | −36.5 | −27.1 | −54.1 |
| NR vs. NaCl + NR [2] | 492 | −25.4 | −23.4 | −41.3 | −59.7 | −30.2 | −26.2 | −26.1 |
| NaCl + NR vs. NaCl + R [3] | −31.3 | −27.2 | −22.4 | −23.9 | −52.7 | −24.1 | −19.1 | −47.3 |
| NR vs. R [4] | −8.42 | −14.0 | −28.1 | −24.7 | −29.3 | −16.6 | −18.2 | −15.2 |

[1] The values for cooked without salt, rinsed (R) were assumed as 100%; [2] The values for cooked without salt, not rinsed (NR) were assumed as 100%; [3] The values for cooked with salt, not rinsed (NaCl + NR) were assumed as 100%; [4] The values for cooked without salt, not rinsed (NR) were assumed as 100%.

## *3.2. Pasta as a Source of Minerals in the Diets of Poles*

### 3.2.1. Sodium, Potassium, Calcium, Magnesium

The supply of Na with one serving of pasta cooked in salted water (NaCl + NR, NaCl + R) is higher ($p < 0.05$) than with one serving of pasta cooked in unsalted water (NR, R) in all consumer age groups (Figure 3). This relationship can be presented as NaCl + NR > NaCl + R > NR = R. In the diet of adults, one serving of pasta will cover the requirement for Na from 0.1% AI (R) to 0.8% AI (NaCl + NR), in the diet of children aged 1 to 6—from 0.1% AI (NR, R) to 0.5% AI (NaCl + NR), in the diet of children aged 7 to 12—from 0.1% AI (NR, R) to 0.6% AI NaCl + NR), and in that of adolescents aged 13 to 18—from 0.1% AI (NR, R) to 0.7% AI (NaCl + NR) (Table 5).

The intake of K with one serving of cooked pasta can be presented as NR > R > NaCl + NR > NaCl + R (Figure 3). Coverage of the daily requirement of adults and adolescents aged 16–18 for K with one serving of pasta ranges from 0.3% AI (NaCl + R) to 0.6% AI (NR), in the diet of children aged 1 to 6—from 0.5% AI (NaCl + R) to ca. 0.9% AI (NR), children aged 7 to 12—from 0.4% AI (NaCl + R) to 0.7% AI (Table 5).

In the diet of adults, one serving of cooked pasta will lead to the intake of Ca in the amount covering from 0.3% RDA (NaCl + R) to ca. 0.5% RDA (NR), in the diet of children aged 1 to 3—from 0.1% RDA (NaCl + R, R) to 0.3% RDA (NaCl + NR, NR), in the diet of children aged 4 to 6—from 0.1% RDA (NaCl + R) to 0.2% RDA (NaCl + NR, NR, R), and in the diet of older children and adolescents—from 0.2% RDA (NaCl + R) to 0.4% RDA (NR) (Table 5).

The supply of Mg with pasta can be presented as NR > R > NaCl + NR > NaCl + R (Figure 3). In Polish norms, the requirement of women and men for Mg differs—one serving of cooked pasta supplies from 11% RDA (NaCl + R) to 25% RDA (NR) of Mg to women, and from 8.5% RDA (NaCl + R) to 19% RDA (NR) (Table 6) to men. In the diet of children aged 1–3, a serving of pasta supplies from 15% RDA (NaCl + R) to 35% RDA (NR) of Mg, in the diet of children aged 4 to 6—from 11.5% RDA (NaCl + R) to 26.2% RDA (NR), and in that of children aged 7 to 12—from 13.5% RDA (NaCl + R) to ca. 30% RDA (NR). According to Polish norms, the requirement for Mg in the case of adolescents aged over 13 depends on the sex. Girls will receive from ca. 9% RDA (NaCl + R) to ca. 20% RDA (NR) of Mg with one serving of pasta, and boys—from ca. 8% RDA (NaCl + R) to 18% RDA (NR) (Table 5).

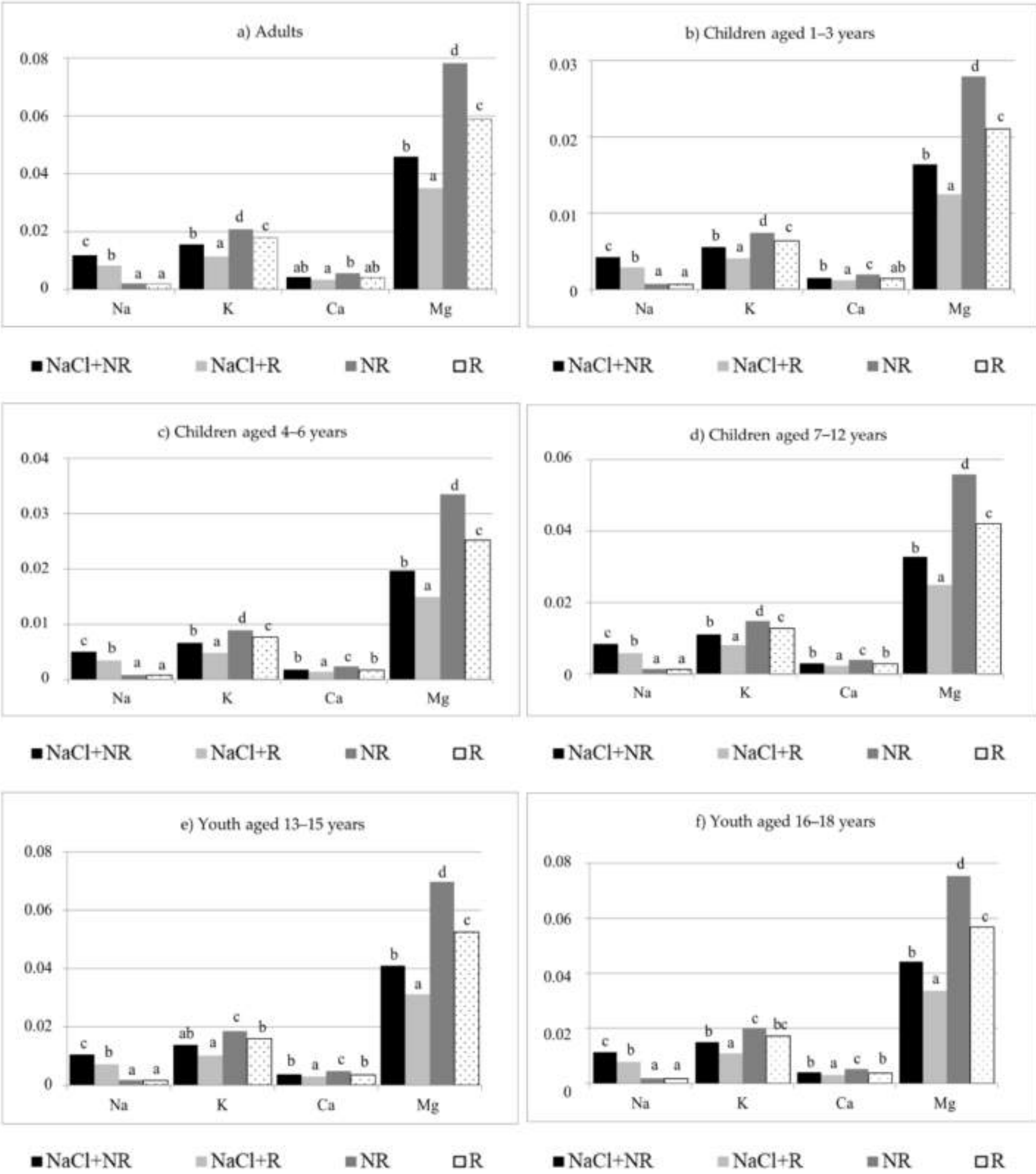


**Figure 3.** Intake of Na, K, Ca, and Mg with analysed pasta per portion, cooked, g. Portion size: (**a**) Adults 140 g [24], (**b**) children aged 1–3 years 50 g [25], (**c**) children aged 4–6 years 60 g [26], (**d**) children aged 7–12 years 100 g [27], (**e**) Youth aged 13–15 years 125 g [28], (**f**) Youth aged 16–18 years 135 g [28]; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; $^{a,b,c,d}$—values with different superscripts differ at $p < 0.05$ by Duncan's test.

3.2.2. Zinc, Copper, Iron, Manganese

The supply of Zn, Cu, Fe, and Mn with a single serving of cooked pasta can be represented as NR > R > NaCl + NR > NaCl + R (Figure 4). In Polish norms, the requirement of women and men for Zn differs—one serving of cooked pasta supplies from 0.6% RDA (NaCl + R) to 3% RDA (NR) of Zn to women, and from 0.4% RDA (NaCl + R) to 2% RDA (NR) (Table 6) to men. In the diet of children aged 1–3, a serving of pasta supplies from 0.5% RDA (NaCl + R) to nearly 3% RDA (NR) of Zn, of children aged 4 to 6—from 0.4% RDA (NaCl + R) to 2% RDA (NR), and in that of children aged over 7 and adolescents—from 0.5% RDA (NaCl + R) to ca. 2.5% RDA (NR).

**Table 5.** Share of pasta products in the supply of Na, K, Ca, and Mg in the diets of respective groups of Poles, g.

| | Mean Share of Pasta in Reference Daily Intake [1], % | | | |
|---|---|---|---|---|
| | **Na** | **K** | **Ca** | **Mg** |
| Adults [2] | | | | |
| NaCl + NR | 0.8 (W, M) | 0.5 (W, M) | 0.4 (W) 0.3 (M) | 14.6 (W) 11.2 (M) |
| NaCl + R | 0.5 (W, M) | 0.3 (W, M) | 0.3 (W) 0.3 (M) | 11.1 (W) 8.5 (M) |
| NR | 0.1 (W, M) | 0.6 (W, M) | 0.5 (W) 0.4 (M) | 24.8 (W) 19.0 (M) |
| R | 0.1 (W, M) | 0.5 (W, M) | 0.4 (W) 0.3 (M) | 18.7 (W) 14.4 (M) |
| Children, age 1–3 [3] | | | | |
| NaCl + NR | 0.5 (W, M) | 0.8 (W, M) | 0.3 (W, M) | 20.0 (W, M) |
| NaCl + R | 0.4 (W, M) | 0.5 (W, M) | 0.1 (W, M) | 15.0 (W, M) |
| NR | 0.1 (W, M) | 0.9 (W, M) | 0.3 (W, M) | 35.0 (W, M) |
| R | 0.1 (W, M) | 0.8 (W, M) | 0.1 (W, M) | 26.3 (W, M) |
| Children, age 4–6 [4] | | | | |
| NaCl + NR | 0.5 (W, M) | 0.6 (W, M) | 0.2 (W, M) | 15.4 (W, M) |
| NaCl + R | 0.3 (W, M) | 0.5 (W, M) | 0.1 (W, M) | 11.5 (W, M) |
| NR | 0.1 (W, M) | 0.8 (W, M) | 0.2 (W, M) | 26.2 (W, M) |
| R | 0.1 (W, M) | 0.7 (W, M) | 0.2 (W, M) | 19.2 (W, M) |
| Children, age 7–12 [5] | | | | |
| NaCl + NR | 0.6 (W, M) | 0.5 (W, M) | 0.3 (W, M) | 17.8 (W, M) |
| NaCl + R | 0.5 (W, M) | 0.4 (W, M) | 0.2 (W, M) | 13.5 (W, M) |
| NR | 0.1 (W, M) | 0.7 (W, M) | 0.4 (W, M) | 30.3 (W, M) |
| R | 0.1 (W, M) | 0.6 (W, M) | 0.3 (W, M) | 22.7 (W, M) |
| Youth, age 13–15 [6] | | | | |
| NaCl + NR | 0.7 (W, M) | 0.5 (W, M) | 0.3 (W, M) | 11.4 (W) 10.0 (M) |
| NaCl + R | 0.5 (W, M) | 0.3 (W, M) | 0.2 (W, M) | 8.6 (W) 7.6 (M) |
| NR | 0.1 (W, M) | 0.6 (W, M) | 0.4 (W, M) | 19.4 (W) 17.1 (M) |
| R | 0.1 (W, M) | 0.5 (W, M) | 0.3 (W, M) | 14.7 (W) 12.9 (M) |
| Youth, age 16–18 [7] | | | | |
| NaCl + NR | 0.7 (W, M) | 0.4 (W, M) | 0.3 (W, M) | 12.2 (W) 10.7 (M) |
| NaCl + R | 0.5 (W, M) | 0.3 (W, M) | 0.2 (W, M) | 9.4 (W) 8.3 (M) |
| NR | 0.1 (W, M) | 0.6 (W, M) | 0.4 (W, M) | 20.1 (W) 18.3 (M) |
| R | 0.1 (W, M) | 0.5 (W, M) | 0.3 (W, M) | 15.8 (W) 13.9(M) |

[1] Based on Jarosz [28]: RDA for Ca, and Mg; AI for Na, and K; Portion size: [2] Adults 140 g [24], [3] children aged 1–3 years 50 g [25], [4] children aged 4–6 years 60 g [26], [5] children aged 7–12 years 100 g [27], [6] youth aged 13–15 years 125 g [28], [7] youth aged 16–18 years 135 g [28]; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; W—women; M—men.

In the diet of adults and adolescents aged 16–18, one serving of cooked pasta supplies from 6.6% RDA (NaCl + R) to ca. 12.5% RDA (NR) of Cu, in the diet of children aged 1 to 3—from 7% RDA (NaCl + R) to ca. 14% RDA (NR), and in that of children aged 7 to 15—from ca. 6% RDA (NaCl + R) to ca. 11.5% RDA (NR) (Table 6).

One serving of pasta in the diet of adult women supplies from ca. 1% RDA (NaCl + R) to ca. 1.6% RDA (NR) of Fe, and in that of men—from ca. 1.7% RDA (NaCl + R) to 2.9% RDA (NR) (Table 6). In the diet of children aged 1–3, one serving of cooked pasta supplies from 0.9% AI (NaCl + R) to 1.5% AI (NR) of Fe, in the diet of children aged 4 to 6—from 0.7% AI (NaCl + R) to 1.3% AI (NR), and in that of children aged over 7—from 1.2% AI (NaCl + R) to ca. 2.1% AI (NR). In Polish norms, the requirement for Fe in the case of adolescents aged over 13 depends on the sex. Girls will receive from ca. 1% RDA (NaCl + R) to ca. 2% RDA (NR) of Fe with one serving of pasta, and boys—from ca. 1.3% RDA (NaCl + R) to ca. 2.2% RDA (NR).

**Table 6.** Share of pasta products in the supply of Zn, Cu, Fe, and Mn in the diets of respective groups of Poles.

| | Mean Share of Pasta in Reference Daily Intake [1], % | | | |
|---|---|---|---|---|
| | **Zn** | **Cu** | **Fe** | **Mn** |
| Adults [2] | | | | |
| NaCl + NR | 1.2 (W) 0.9 (M) | 8.9 (W, M) | 1.2 (W) 2.6 (M) | 13.5 (W) 10.6 (M) |
| NaCl + R | 0.6 (W) 0.4 (M) | 6.7 (W, M) | 1.0 (W) 1.7 (M) | 7.1 (W) 5.6 (M) |
| NR | 3.0 (W) 2.2 (M) | 12.7 (W, M) | 1.6 (W) 2.9 (M) | 18.3 (W) 14.3 (M) |
| R | 2.1 (W) 1.5 (M) | 10.7 (W, M) | 1.3 (W) 2.4 (M) | 15.4 (W) 12.1 (M) |
| Children, age 1–3 [3] | | | | |
| NaCl + NR | 1.1 (W, M) | 9.7 (W, M) | 1.1 (W, M) | 7.3 (W, M) |
| NaCl + R | 0.5 (W, M) | 7.3 (W, M) | 0.9 (W, M) | 3.8 (W, M) |
| NR | 2.8 (W, M) | 13.7 (W, M) | 1.5 (W, M) | 9.8 (W, M) |
| R | 2.0 (W, M) | 11.3 (W, M) | 1.2 (W, M) | 8.3 (W, M) |
| Children, age 4–6 [4] | | | | |
| NaCl + NR | 0.8 (W, M) | 8.5 (W, M) | 0.9 (W, M) | 6.9 (W, M) |
| NaCl + R | 0.4 (W, M) | 6.5 (W, M) | 0.7 (W, M) | 3.7 (W, M) |
| NR | 2.0 (W, M) | 12.3 (W, M) | 1.3 (W, M) | 9.4 (W, M) |
| R | 1.4 (W, M) | 10.3 (W, M) | 1.0 (W, M) | 7.9 (W, M) |
| Children, age 7–12 [5] | | | | |
| NaCl + NR | 1.0 (W, M) | 8.1 (W, M) | 1.5 (W, M) | 10.2 (W, M) |
| NaCl + R | 0.5 (W, M) | 6.1 (W, M) | 1.2 (W, M) | 5.4 (W, M) |
| NR | 2.6 (W, M) | 11.7 (W, M) | 2.1 (W, M) | 13.8 (W, M) |
| R | 1.8 (W, M) | 9.7 (W, M) | 1.7 (W, M) | 11.7 (W, M) |
| Youth, age 13–15 [6] | | | | |
| NaCl + NR | 0.9 (W) 0.8 (M) | 8.0 (W, M) | 1.3 (W) 1.6 (M) | 13.5 (W) 9.8 (M) |
| NaCl + R | 0.4 (W) 0.4 (M) | 6.0 (W, M) | 1.0 (W) 1.3 (M) | 7.1 (W) 5.0 (M) |
| NR | 2.4 (W) 2.0 (M) | 11.3 (W, M) | 1.7 (W) 2.2 (M) | 18.3 (W) 13.3 (M) |
| R | 1.7 (W) 1.4 (M) | 9.4 (W, M) | 1.4 (W) 1.8 (M) | 15.6 (W) 11.3 (M) |
| Youth, age 16–18 [7] | | | | |
| NaCl + NR | 1.0 (W) 0.8 (M) | 8.6 (W, M) | 1.4 (W) 1.7 (M) | 14.6 (W) 10.6 (M) |
| NaCl + R | 0.5 (W) 0.4 (M) | 6.6 (W, M) | 1.1 (W) 1.4 (M) | 7.8 (W) 5.6 (M) |
| NR | 2.5 (W) 2.1 (M) | 12.2 (W, M) | 1.9 (W) 2.3 (M) | 19.8 (W) 14.4 (M) |
| R | 1.8 (W) 1.5 (M) | 10.2 (W, M) | 1.5 (W) 1.9 (M) | 16.8 (W) 12.2 (M) |

[1] Based on Jarosz [28]: RDA for Ca, and Mg; AI for Na, and K; Portion size: [2] Adults 140 g [24], [3] children aged 1–3 years 50 g [25], [4] children aged 4–6 years 60 g [26], [5] children aged 7–12 years 100 g [27], [6] youth aged 13–15 years 125 g [28], [7] youth aged 16–18 years 135 g [28]; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; W—women; M—men.

In Polish norms, the requirement for Mn in the case of adolescents aged over 13 and adults also depends on the sex. One serving of cooked pasta will supply from 7.1% AI (NaCl + R) to 18.3% AI (NR) of Mn to adult women, and from 5.6% AI (NaCl + R) to 14.3% AI (NR) (Table 6) to men. Girls aged 13–15 will receive from 7.1% AI (NaCl + R) to 18.3% AI (NR) of Mn with one serving of pasta, and boys—from 5.0% AI (NaCl + R) to 13.3% AI (NR). In turn, adolescents aged 16–18 will receive from ca. 8% AI (NaCl + R) to ca. 20% AI (NR) of Mn (women) with one serving of pasta, and from ca. 6% AI (NaCl + R) to more than 14% AI (NR) (men). In the diet of children aged 1–6, one serving of pasta will supply from ca. 4% AI (NaCl + R) to ca. 10% AI (NR) of Mn, and in that of children aged 7 to 12—from 5.4% AI (NaCl + R) to ca. 14% AI (NR).

Table 7 summarizes relationships between the content of minerals in the analysed pasta for each cooking method.

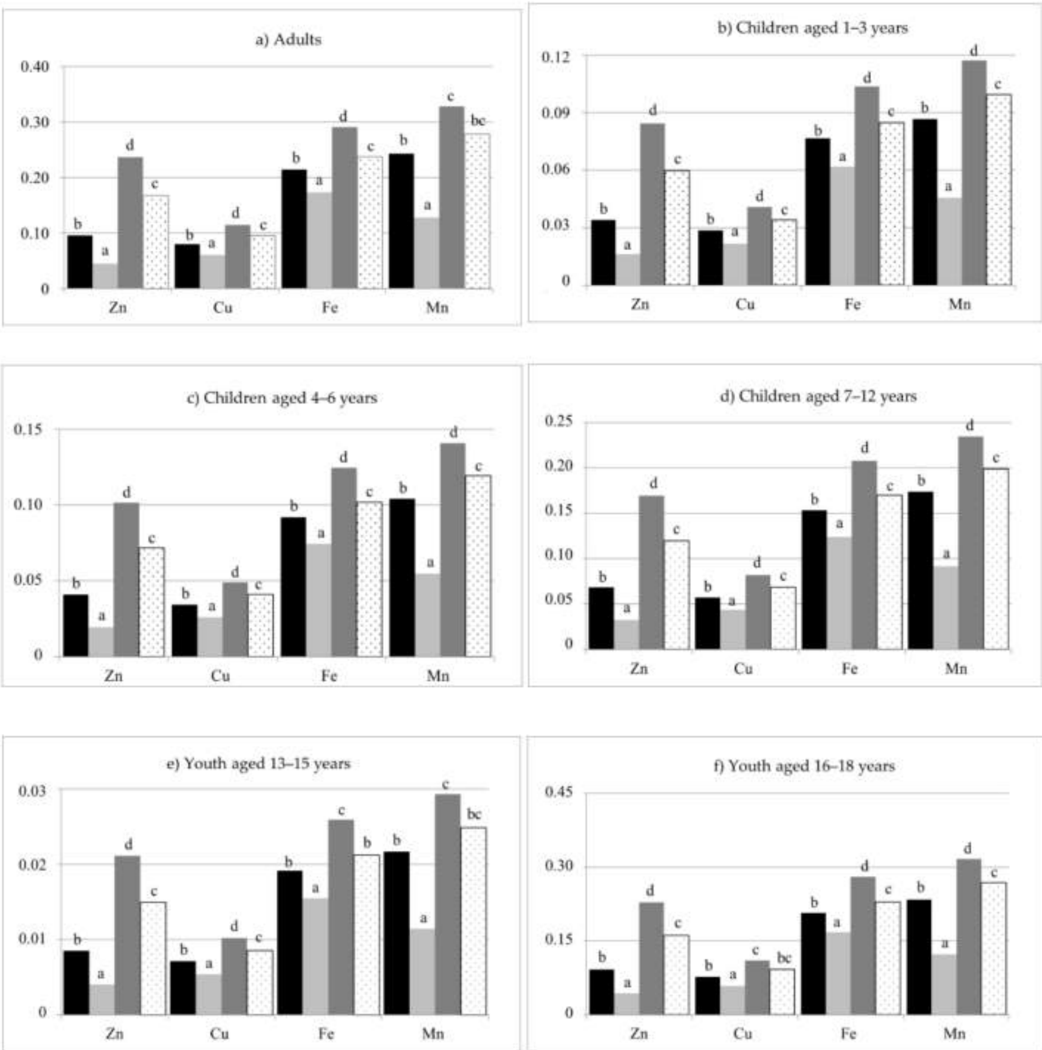


**Figure 4.** Intake of Zn, Cu, Fe, and Mn with analysed pasta per portion, cooked, mg. Portion size: (**a**) Adults 140 g [24], (**b**) children aged 1–3 years 50 g [25], (**c**) children aged 4–6 years 60 g [26], (**d**) children aged 7–12 years 100 g [27], (**e**) children aged 13–15 years 125 g [28], (**f**) children aged 16–18 years 135 g [28]; NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed; $^{a,b,c,d}$—values with different superscripts differ at $p < 0.05$ by Duncan's test.

**Table 7.** Ranking of the content of minerals for each cooking method.

| Cooking Parameters | |
|---|---|
| NaCl + NR | Mg > K > Na > Ca > Mn > Fe > Zn > Cu |
| NaCl + R | Mg > K > Na > Ca > Fe > Mn > Cu > Zn |
| NR | Mg > K > Ca > Na > Mn > Fe > Zn > Cu |
| R | Mg > K > Ca > Na > Mn > Fe > Zn > Cu |

NaCl + NR—cooked with salt and not rinsed; NaCl + R—cooked with salt and rinsed; NR—cooked without salt and not rinsed; R—cooked without salt and rinsed.

## 4. Discussion

### *4.1. How Culinary Processes Affect the Content of Minerals in Pasta*

The process of cooking cereal products modifies their chemical composition as a result of the removal or absorption, and in particular, the content, of minerals that are easily soluble in water [23,30]. In the presented study, cooking pasta in salted water increased the content of Na and decreased that of all other analysed minerals in comparison to raw pasta. In turn, pasta cooked in unsalted water contained less analysed minerals (all except K) than raw pasta. Furthermore, cooking pasta in unsalted water led to a decreased content of Na and other minerals in comparison to pasta cooked in salted water. Due to increasing the content of Na in water by adding salt, Na from the solution penetrates into the product, thereby reducing the content of other minerals, while cooking in unsalted water causes Na to penetrate from the product into the water. The degree of penetration of minerals from pasta into water and the other way round during cooking depends on the content of Na in the water [24]. The studies by Albrecht et al. [23] showed that cooking pasta in salted water (from 4.4 to ca. 6.0 g NaCl per 1 litre) increased the concentration of Na in pasta about 100 times in comparison to its concentration in pasta cooked in unsalted water, whereas cooking in unsalted water reduced the content of Na by 16–69% in comparison to raw pasta. In turn, rinsing of cooked pasta with running water decreased the content of Na by ca. 30% [23]. The quoted study also demonstrated K > Mg > Ca > Fe > Zn > Mn > Cu in cooked pasta, irrespective of whether it was cooked in water with or without salt. In the presented study, the addition of salt increased the content of Na at the expense of Ca, while rinsing pasta cooked in salted water changed the relationship between the microelements: the content of Fe was higher than that of Mn, and that of Cu was higher than Zn, while the use of other experimental factors resulted in Mn > Fe > Zn > Cu. According to Cubadda et al. [31], cooked Italian pasta contained Fe > Zn > Mn > Cu. Bianchi et al. [24] added different amounts of salt to water used for cooking pasta: 0 g, 3.17 g or 6.34 g of salt per litre, which led to a linear increase in the content of Na in the pasta. In this study, using water without salt reduced the content of Na in cooked pasta by 48%, in comparison to the content in pasta cooked in water with 3.17 g of salt and by 99% in comparison to the content in pasta cooked in water with 6.34 g of salt. Similarly, Jambrec et al. [32] demonstrated that when pasta is cooked in unsalted water, the content of Na in the product is reduced by about 42% in comparison to the raw product.

According to Manthey and Hall [30], cooking pasta enriched with buckwheat meal in distilled water reduces the content of K, Cu, and Zn by 62%, 45%, and 11%, respectively. In the opinion of these authors, cooking generally had no influence on the content of Fe and Mg, while the content of Ca and Mn after cooking was similar or higher than prior to cooking. According to Jambrec et al. [33], in the course of cooking, the pasta loses ca. 50% K. The losses of Ca and Mg were not significant; the content of Ca in cooked pasta was even higher than in raw pasta, which, according to the authors, can be attributed to a change in the proportions of ingredients (flushing of starch and protein). Our own study showed that the content of Fe, Mg, Ca, and Mn after cooking was lower than in raw pasta, both in rinsed and non-rinsed, and in salted and unsalted samples. The unchanged content of certain minerals does not mean that they were not flushed from pasta during cooking, but rather, were leached in the proportion similar to other minerals [30]. Other reference sources suggest that the decrease in the content of minerals by 10–30% during traditional cooking of pasta was typical, except for K of which 67% were retained [34]. The study by Albrecht et al. [23] noted that the content of K and Cu decreased by 58% and 88%, respectively, when pasta was traditionally cooked in salted water. Similarly, Yaseen [34] and Ranhotra [22] reported that about 67% of K is flushed from traditionally cooked pasta. In our own study, the highest loss of K was recorded for pasta cooked in salted water and then rinsed (NaCl + R)—ca. 37% in comparison with raw pasta. Ikeda and Shimizu [35] observed that ca. 20% of Zn is flushed from buckwheat pasta in cooking. In our own study, the loss of this element in cooking reached up to 89% for pasta cooked in salted water and then rinsed (NaCl + R). Cubadda et al. [31] found an increased content of Ca in pasta cooked in drinking water, both salted and unsalted. When pasta is cooked in distilled water, the increase of Ca can be explained by the flushing of starch and soluble proteins, which alters the direct composition of the cooked pasta [36].

In the presented studies, rinsing of the cooked pasta decreased the content of all the analysed minerals. The differences were particularly high for Na, the content of which decreased by up to 31% for pasta cooked in salted water. Other authors obtained similar results, finding that rinsing of the cooked pasta with running water reduces the content of Na by about 30% [23,24]. According to Ranhotra et al. [22], the retention of Na while cooking pasta in unsalted distilled water can be from 7% up to 89%, for other minerals (K, Ca, Mg)—from 25% to 114%, and for microelements (Zn, Cu, Fe, Mn)—from 62% to 119%. Retention of some elements was higher than 100% in the quoted study. This can be due to the fact that apparent retention, not taking into account the loss of solids in cooking, often shows falsely high values [37]. Another reason may be the highly mineralized tap water in Lublin [38], from which the minerals were transferred to the cooked product. It is possible that hard tap water may increase the retention of minerals in prepared meals. Another reason may be changes in the proportion of minerals caused by the transfer of minerals from water to pasta and from being rinsed from pasta to water. The third reason may be the shape of the pasta. In our own study, six types of pasta were used, which are short and have many recesses, which means that their surface is large, larger than pasta with a smooth surface, such as spaghetti. The research showed that the shape and type of pasta significantly ($p < 0.05$) influenced the level of minerals in pasta, also when cooked (Figures 1 and 2). Accordingly, the shape of the pasta can also influence the size of the retention factor. This may be explained by the fact that in the studies by Ranhotra et al. [22] and Albrecht et al. [23], the results were lower than those found in our own study, because the cited authors used other types of pasta—long, with regular shapes (spaghetti, noodles, macaroni).

*4.2. Pasta as a Source of Minerals in the Diet*

Cereal products are an important source of minerals in the diet of Poles. Their share in covering the requirement for respective elements can be presented as: Mn > Cu > Na > Fe > Zn > Mg > K > Ca [2–4]. Considering a variety of cereal products (bread, groats, rice, and cereal flakes), the maximum share of pasta in the supply of the analysed minerals is 5% [3,4,39]. Poles do not eat a lot of pasta—on average, 0.4 kg per capita [1]. Still, in Poland—like in many countries—pasta is the second most often consumed cereal food [1,39]. However, based on the results of our own study, it can be concluded that pasta is an important source of Mg, Cu, and Mn in the diet of Poles. At the same time, it was observed that the best source of minerals was pasta cooked in unsalted water without rinsing, so this is the best method of culinary treatment of pasta. Children receive the highest amount of Mg and Cu with one serving of pasta—above 26% RDA and above 12% RDA, respectively. On the other hand, pasta is the best source of Mn for adults and adolescents—it supplies 18–20% AI. Cubadda et al. [31] estimated that one serving of pasta available on the Italian market, weighing 80 g before cooking, would cover the daily requirement for minerals (RDA) of an adult as follows: 18% Cu, 10–14% Zn (for men and women, respectively), 5–9% Fe (for women and men, respectively). Ranhotra et al. [22] found that pasta in the diet of adult Americans is a good source of Mg, Zn, Fe, Cu, and Mn by comparing the measured values against American nutritional guidelines.

The diets of Poles are deficient in most minerals. Most frequently, it is noted that the diets of children, adolescents, and the elderly contain insufficient levels of Cu and Mg [40–42]. In addition, it was demonstrated that in women's breastmilk, the content of Cu was too low, due to a deficiency of this element in their diet [43]. The deficiency of Mn in the human diet around the world is very rare, while an excessive intake of Mn with food can be a problem. The toxicity of Mn results primarily from its prooxidative effect, leading to damage of the cells of the extrapyramidal system, in particular of the dopamine system, which can lead to the development of Parkinson's disease [44,45]. The identified toxic level of Mn is 9–11 mg for adults and 2–6 mg for children [46]. The diet of Poles contains excessive amounts of Mn; according to some data, the intake of Mn is twice the requirement for this element [38,47]. Our own study showed that rinsing pasta after cooking decreases the content of Mn in it. Although some sources mention an excessive intake of manganese from food, in our own study, the upper safety limit was not exceeded, even for non-rinsed and unsalted pasta.

Although our own studies do not imply a significant share of pasta in the supply of Na (less than 1% AI for all analysed age groups), a significant effect of adding salt to water while cooking on the supply of Na can be observed. The results clearly indicate that the least Na will be supplied with pasta cooked in unsalted water. This is particularly important, since the intake of Na as table salt in the diet of Poles is excessive, and every method to reduce the consumption of Na is important, all the more so because correct nutritional habits are of key importance. Studies involving people with hypertension showed that although the respondents were aware of the recommendations to reduce the consumption of salt, most of them exceeded the recommended levels [48]. Children and adolescents also consume too much salt—on average, more than 3 g a day [49,50]. As early as 2006, the World Health Organization recommended that the daily intake of Na should not exceed 2 g, which is an amount contained in 5 g of table salt, to reduce the risk of cardiovascular diseases [51]. In Western societies, the consumption of salt ranges from 8 to 12 g, which is several times higher than the physiological requirement of the body amounting to about 0.5 g [52]. In Poland, two times the recommended norm of salt is consumed mainly as table salt added to meals [29]. A tendency to consume excessive amounts of salt develops at an early stage of life, when adults—guided by their own taste—use excessive amounts of salt when preparing food for children [53]. The intake of Na can be decreased by gradually decreasing the content of this element in the most popular foodstuffs or changing the culinary treatment method, that is, adding salt after cooking, and not using salt in cooking, such as for pasta or groats. Studies in Peru showed that as many as 84% of people preparing meals at home were willing to reduce the use of salt during culinary processes [54].

## 5. Conclusions

The most efficient way of reducing the intake of Na and increasing that of deficient minerals with cereal products is not adding table salt to water in which pasta is cooked, even if the producer recommends adding salt to water. Only additions to pasta, such as sauces, should be seasoned, whilst one should reduce the amount of salt when seasoning, and instead of salt, use herbs and natural spices for flavour. American studies showed that the diet of people eating pasta is richer in deficit nutrients, including minerals, but on the condition that the use of table salt and saturated fatty acids is reduced in cooking [55]. Because Na in the form of table salt is very soluble in water and easily diffused, the recommendation not to add salt to water when cooking may also apply to other foodstuffs, such as groats, rice, vegetables, and beans. This problem should be examined in detail. In turn, rinsing pasta after cooking leads to the flushing of minerals and decreases the nutritional value of pasta, so this culinary treatment should be discouraged. The right culinary processing of food can reduce the risk of diet-related diseases of civilisation. There is a need for more research regarding the relationship between the type of cooked pasta and the content of minerals.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/foods10092131/s1, Table S1: Characteristic of analysed products, Table S2: RDA and AI values for minerals according to Polish norms, mg, Table S3: Pearson correlation coefficients for NaCl + NR, Table S4: Pearson correlation coefficients for NaCl + R, Table S5: Pearson correlation coefficients for NR, Table S6. Pearson correlation coefficients for R.

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**Table S1.** Characteristic of analysed products.

| Pasta type | Ingredients | Cooking time, min. | Salt amount in raw product, g per kg * | Weight of pasta before cooking (g) | Weight of pasta after cooking (g) ** |
|---|---|---|---|---|---|
| Penne | Wheat flour | 8 | 0 | 100 | 319 |
| | Wheat flour, durum flour | 9 | < 0.01 | 100 | 306 |
| | Wheat flour, turmeric | 9 | < 0.01 | 100 | 294 |
| | Wholemeal wheat flour | 6 | 0.1 | 100 | 312 |
| | Wholemeal durum flour | 7 | 0.1 | 100 | 318 |
| | Wholemeal spelt flour | 7 | 0.3 | 100 | 320 |
| | Wholemeal durum flour | 13 | 0.15 | 100 | 312 |
| Ditalini | Durum flour | 12 | < 0.1 | 100 | 301 |
| | Wheat flour, durum flour | 10 | 0 | 100 | 311 |
| | Wheat flour | 5 | 0 | 100 | 290 |
| | Wholemeal wheat flour, durum flour | 10 | 0.01 | 100 | 306 |
| | Wholemeal durum flour, wheat flour; BIO | 10 | 0.05 | 100 | 295 |
| Gigli | Durum flour | 5 | 0 | 100 | 258 |
| | Wheat flour | 6 | 0 | 100 | 251 |
| | Spelt flour | 8 | 0 | 100 | 274 |
| | Wholemeal durum flour, wholemeal barley flour, amaranth flour | 7 | 0.2 | 100 | 258 |
| | Wholemeal durum flour, wheat flour; BIO | 5 | 0.5 | 100 | 250 |
| Creste | Durum flour, wheat flour, eggs, water | 11 | 0.04 | 100 | 305 |
| | Wheat flour | 5 | 0 | 100 | 303 |
| | Durum flour | 12 | 0 | 100 | 300 |
| | Wheat flour, durum flour, eggs | 8 | 0.07 | 100 | 314 |
| Fusilli | Rice flour, corn starch, tapioca starch | 7 | 0.02 | 100 | 321 |
| | Wheat flour | 6 | 0 | 100 | 320 |
| | Wheat flour | 9 | 0 | 100 | 314 |
| | Wholemeal wheat flour | 7 | 0.01 | 100 | 313 |
| | Wholemeal spelt flour | 9 | < 0.01 | 100 | 334 |
| | Wholemeal durum flour | 9 | 0.5 | 100 | 321 |
| | Wholemeal wheat flour | 4 | 0.011 | 100 | 321 |
| Filini | Wheat flour, eggs, turmeric | 3 | 0.09 | 100 | 255 |
| | Spelt flour, turmeric | 5 | 0.015 | 100 | 263 |
| | Spelt flour; BIO | 5 | 0.015 | 100 | 265 |
| | Spelt flour | 4 | 0 | 100 | 264 |
| | Wholemeal spelt flour | 4 | 0.1 | 100 | 261 |
| | Wholemeal spelt flour; BIO | 8 | < 0.01 | 100 | 271 |
| | Wholemeal spelt flour; BIO | 8 | 0.01 | 100 | 251 |

* Values declared by producer; *** Mean values

**Tabela S2.** RDA and AI values for minerals according to Polish standards, mg.

| | Na | K | Ca | Mg | Zn | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|
| | **AI** | **AI** | **RDA** | **RDA** | **RDA** | **RDA** | **RDA** | **AI** |
| Adults | 1500 (W, M) | 3500 (W, M) | 1200 (W) 1000 (M) | 320 (W) 420 (M) | 8 (W) 11 (M) | 0.9 (W, M) | 18 (W) 10 (M) | 1.8 (W) 2.3 (M) |
| Children, age 1–3 | 750 (W, M) | 800 (W, M) | 700 (W, M) | 80 (W, M) | 3 (W, M) | 0.3 (W, M) | 7 (W, M) | 1.2 (W, M) |
| Children, age 4–6 | 1000 (W, M) | 1100 (W, M) | 1000 (W, M) | 130 (W, M) | 5 (W, M) | 0.4 (W, M) | 10 (W, M) | 1.5 (W, M) |
| Children, age 7–12 | 1300 (W, M) | 2400 (W, M) | 1300 (W, M) | 240 (W, M) | 8 (W, M) | 0.7 (W, M) | 10 (W, M) | 1.6 (W) 1.9 (M) |
| Children, age 13–15 | 1500 (W, M) | 3000 (W, M) | 1300 (W, M) | 360 (W) 410 (M) | 9 (W) 11 (M) | 0.9 (W, M) | 15 (W) 12 (M) | 1.6 (W) 2.2 (M) |
| Children, age 16–18 | 1500 (W, M) | 3500 (W, M) | 1300 (W, M) | 360 (W) 410 (M) | 9 (W) 11 (M) | 0.9 (W, M) | 15 (W) 12 (M) | 1.6 (W) 2.2 (M) |

**Table S3.** Pearson correlation coefficients for NaCl+NR.

| | **Na** | **K** | **Ca** | **Mg** | **Zn** | **Cu** | **Fe** | **Mn** |
|---|---|---|---|---|---|---|---|---|
| Na | 1.000 | -0.403 | 0.729 | 0.291 | -0.088 | -0.622 | -0.165 | -0.674 |
| K | -0.403 | 1.000 | -0.218 | 0.723 | 0.662 | -0.175 | -0.499 | 0.827 |
| Ca | 0.729 | -0.218 | 1.000 | 0.380 | 0.205 | -0.547 | -0.513 | -0.357 |
| Mg | 0.291 | 0.723 | 0.380 | 1.000 | 0.783 | -0.510 | -0.790 | 0.288 |
| Zn | -0.088 | 0.662 | 0.205 | 0.783 | 1.000 | -0.136 | -0.732 | 0.322 |
| Cu | -0.622 | -0.175 | -0.547 | -0.510 | -0.136 | 1.000 | 0.068 | -0.101 |
| Fe | -0.165 | -0.499 | -0.513 | -0.790 | -0.732 | 0.068 | 1.000 | -0.107 |
| Mn | -0.674 | 0.827 | -0.357 | 0.288 | 0.322 | -0.101 | -0.107 | 1.000 |

value *r*; strong correlations are marked in red; NaCl + NR – cooked with salt and not rinsed

**Table S4.** Pearson correlation coefficients for NaCl+R.

| | Na | K | Ca | Mg | Zn | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|
| Na | 1.000 | -0.403 | 0.748 | 0.129 | -0.117 | -0.571 | -0.302 | -0.684 |
| K | -0.403 | 1.000 | -0.413 | 0.803 | 0.927 | -0.096 | -0.506 | 0.374 |
| Ca | 0.748 | -0.413 | 1.000 | 0.121 | -0.088 | -0.541 | -0.411 | -0.517 |
| Mg | 0.129 | 0.803 | 0.121 | 1.000 | 0.953 | -0.345 | -0.882 | -0.041 |
| Zn | -0.117 | 0.927 | -0.088 | 0.953 | 1.000 | -0.330 | -0.722 | 0.242 |
| Cu | -0.571 | -0.096 | -0.541 | -0.345 | -0.330 | 1.000 | 0.178 | -0.119 |
| Fe | -0.302 | -0.506 | -0.411 | -0.882 | -0.722 | 0.178 | 1.000 | 0.402 |
| Mn | -0.684 | 0.374 | -0.517 | -0.041 | 0.242 | -0.119 | 0.402 | 1.000 |

value *r*; strong correlations are marked in red; NaCl + R – cooked with salt and rinsed

**Table S5.** Pearson correlation coefficients for NR.

| | **Na** | **K** | **Ca** | **Mg** | **Zn** | **Cu** | **Fe** | **Mn** |
|---|---|---|---|---|---|---|---|---|
| Na | 1.000 | 0.591 | 0.757 | 0.284 | 0.613 | -0.483 | -0.492 | 0.023 |
| K | 0.591 | 1.000 | 0.577 | 0.400 | 0.536 | -0.618 | -0.380 | 0.747 |
| Ca | 0.757 | 0.577 | 1.000 | 0.440 | 0.538 | -0.452 | -0.172 | 0.012 |
| Mg | 0.284 | 0.400 | 0.440 | 1.000 | 0.824 | -0.266 | -0.639 | 0.102 |
| Zn | 0.613 | 0.536 | 0.538 | 0.824 | 1.000 | -0.093 | -0.901 | 0.243 |
| Cu | -0.483 | -0.618 | -0.452 | -0.266 | -0.093 | 1.000 | -0.078 | -0.130 |
| Fe | -0.492 | -0.380 | -0.172 | -0.639 | -0.901 | -0.078 | 1.000 | -0.267 |
| Mn | 0.023 | 0.747 | 0.012 | 0.102 | 0.243 | -0.130 | -0.267 | 1.000 |

value *r*; strong correlations are marked in red; NR – cooked without salt and not rinsed

**Table S6.** Pearson correlation coefficients for R.

| | Na | K | Ca | Mg | Zn | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|
| Na | 1.000 | 0.537 | 0.968 | 0.602 | 0.544 | -0.336 | -0.525 | -0.073 |
| K | 0.537 | 1.000 | 0.657 | 0.564 | 0.437 | -0.602 | -0.346 | 0.634 |
| Ca | 0.968 | 0.657 | 1.000 | 0.770 | 0.675 | -0.397 | -0.616 | 0.059 |
| Mg | 0.602 | 0.564 | 0.770 | 1.000 | 0.914 | -0.190 | -0.767 | 0.261 |
| Zn | 0.544 | 0.437 | 0.675 | 0.914 | 1.000 | 0.172 | -0.888 | 0.335 |
| Cu | -0.336 | -0.602 | -0.397 | -0.190 | 0.172 | 1.000 | -0.130 | 0.049 |
| Fe | -0.525 | -0.346 | -0.616 | -0.767 | -0.888 | -0.130 | 1.000 | -0.082 |
| Mn | -0.073 | 0.634 | 0.059 | 0.261 | 0.335 | 0.049 | -0.082 | 1.000 |

value *r*; strong correlations are marked in red; R – cooked without salt and rinsed

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# The effect of pasta cooking method (unsalted versus salted water) on sodium absorption: an *in vitro* digestion study

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## Abstract

Information on sodium absorption during digestion in various sections of the gastrointestinal tract is limited. Our study aimed to determine whether the cooking method (water with 16 g of salt per 1 L vs. unsalted water) affects sodium bioavailability during *in vitro* digestion. We analysed five types of pasta that differed in composition. We demonstrated that sodium absorption from cooked pasta in the human gastrointestinal tract ranges from approximately 62% (unsalted water) to nearly 100% (salted water). We also found that the highest sodium absorption occurred in the small intestine, regardless of cooking method or pasta type. Statistically significant higher percent of sodium absorption was confirmed for pasta cooked in salted water compared to that cooked in unsalted water for three of five types of pasta: pasta with seaweed, durum wheat pasta, and whole grain wheat-rye pasta. Cooking in salted water had a significant impact on increasing sodium bioavailability in the gastrointestinal tract, and the degree of sodium absorption from pasta was positively correlated with the sodium content of the product, which in turn depended on the salt concentration in the cooking water. In our study, more than 90% of the Na was absorbed from all types of pasta cooked in salted water.

**Keywords:** sodium, Na, *in vitro* digestion, pasta, absorption

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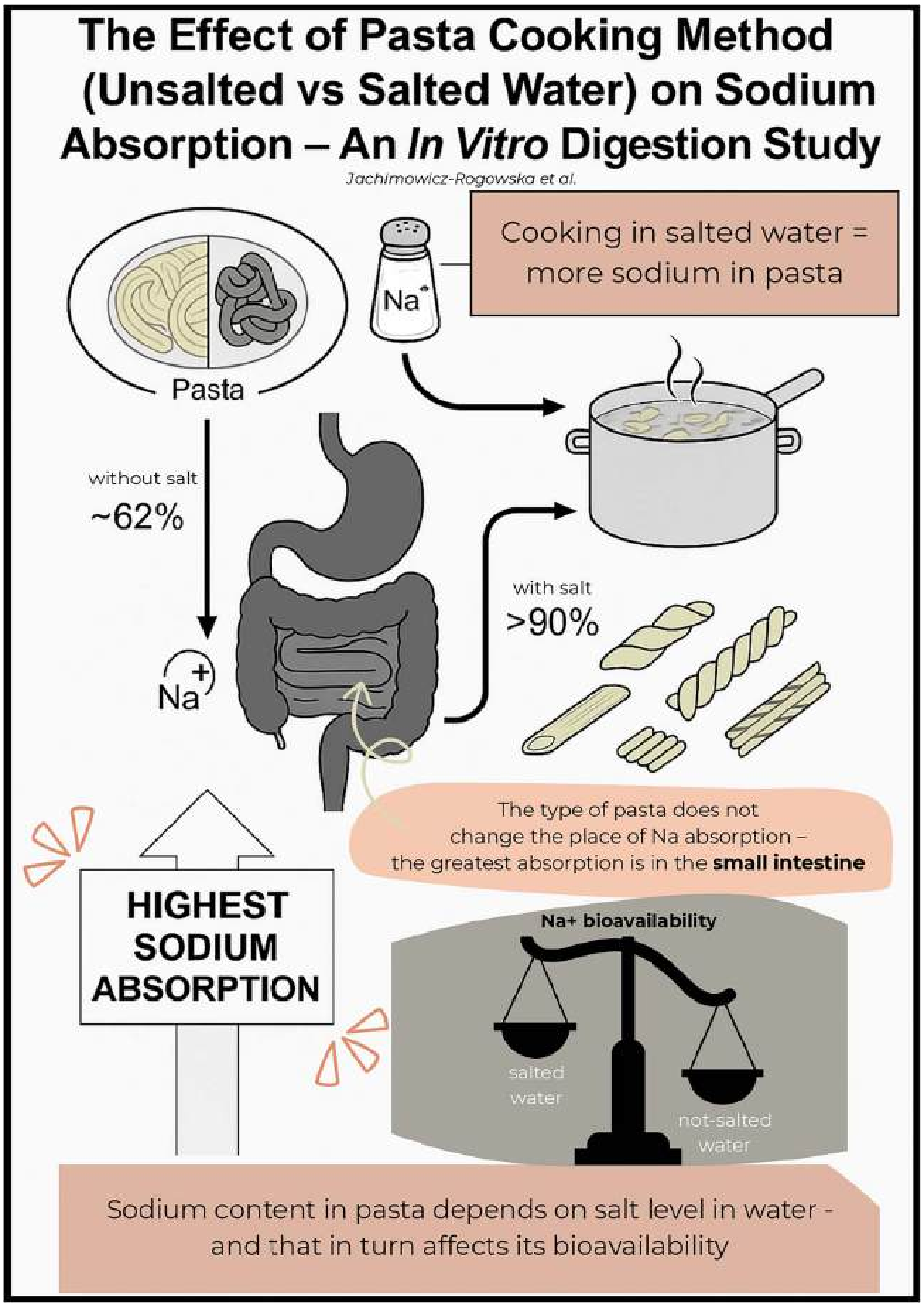
## Graphical abstract




## Introduction

Pasta is a widely consumed food product worldwide and is the basis of the Mediterranean diet (Dello Russo et al., 2021). It is valued for its ease of preparation, long shelf life, low cost, simplicity of cooking, and low glycaemic index (GI), which, depending on the type of pasta, typically ranges between 32 and 40. It is predominantly composed of carbohydrates (~70%–72%), proteins (~12%–15%), lipids (~1.5%–4.0%), and dietary fibre (~2.8%–3.8%) (Dello Russo et al., 2021; Di Pede et al., 2021). The mineral content of cooked pasta depends on the culinary processing method, particularly the use of salt in cooking water and rinsing of the cooked product (Jachimowicz et al., 2021).

Sodium intake has been debated for several years. Although it plays a key role in the human body, including the regulation of water-electrolyte balance and maintenance of acid–base equilibrium, excessive intake may lead to serious health issues, such as an increased risk of hypertension or cardiovascular disease (Farquhar et al., 2015; Mozaffarian, 2016). Pasta requires cooking before consumption. It has been shown that the sodium content in dry pasta is minimal and does not exceed 0.6 g/100 g (depending on the type), but this level may rise significantly when salt is added during the cooking process (Jachimowicz et al., 2021). Most pasta manufacturers recommend cooking pasta in salted water, and packaging often includes the "salt to taste" suggestion, which contributes to an increase in the sodium content of the prepared dish (Hunter et al., 2022; Jachimowicz et al., 2021). Research has shown that 11% of Na in the human diet originates from salt added during food preparation, and processed pasta is among the primary food products that contribute to excessive sodium intake (Hunter et al., 2022; Quader et al., 2017). There is a paucity of research on the bioavailability of Na in pasta and other food products within the gastrointestinal tract. Studies in this area may help to improve our understanding of the relationship between the salt content of food products and Na absorption, which can support the development of strategies aimed at reducing table salt intake.

Cooking cereal-based products induces changes in their chemical composition, particularly in minerals that are highly water-soluble (Bianchi et al., 2019; Jachimowicz et al., 2021). Food undergoes structural and physicochemical transformations as it passes through different parts of the gastrointestinal tract, including the oral cavity, stomach, small intestine, and colon (McClements et al., 2016). Digestive enzymes and variations in pH across these sections can alter such properties, potentially affecting the *in vivo* absorption process (Baranowska-Wójcik et al., 2022a). Numerous studies have used *in vitro* human intestinal models to evaluate the absorption and transport of nutrients in the human body (Baranowska-Wójcik et al., 2022b; Minekus et al., 2014). It was assumed that the higher the sodium content in cooked pasta, the higher the percent of sodium absorption from pasta in the gastrointestinal tract. In our study, we simulated the digestion of five types of fusilli pasta (each with a different formulation) using an advanced *in vitro* gastrointestinal model to determine whether the cooking method (with or without salt) and the type of pasta can influence sodium absorption during digestion.

## Materials and methods

Five different types of fusilli pasta, varying in composition (Table 1), were purchased in August 2024 from grocery stores in Lublin, Eastern Poland. The considered pasta samples differ in terms of the formula composition of pasta. The varied samples were designed to check whether the differences in composition (e.g., pasta additives, higher fibre content in wholegrain products) had an impact on digestion. On the other hand, these types of pasta are popular and easily available in Poland and around the world. According to the manufacturer's declarations on the packaging, the formulations of all products were salt-free. From each pasta type, 100 g samples (weighed to one decimal place) were prepared and cooked for the time recommended by the manufacturer in potable water either (1) without the addition of salt or (2) with the addition of table salt at a concentration of 16 g/L. After cooking, the pasta was drained using a plastic sieve. After 2 min, 100 g of drained pasta was weighed and subjected to digestion.

### *In vitro* digestion

The method was adopted by Minekus et al. (2014) with a few modifications (Baranowska-Wójcik et al., 2022b). Pasta (100 g) was mixed in the digestion chamber (three jacketed glass tanks, each 1 L in volume) with 35 ml of Simulated Salivary Fluid, and 2 ml of $\alpha$-amylase solution containing 451 units of the enzyme (human saliva Type IX-A, 1,000–3,000 units/mg protein Sigma) was added. Then, 0.25 ml 0.3 M/L $CaCl_2$ solution and 9.75 ml DDI water were added, and the samples were kept at 37 °C with stirring at 50 rpm for 2 min (end of the mouth phase). Twenty millilitres were used for the analysis (end of the mouth phase). In the case of each "digested" sample (vessel), a 0.2 $\mu$m membrane (VF05P7 PES, Sartorius, France) was connected to the digestion vessel with a tube, and the return tube was put back into the tank. The slow working mode was maintained (Cole-Palmer peristaltic pump, approximately 3–5 ml/min), and a microfiltration membrane was used to simulate bioaccessibility and peristaltic movements in the gastrointestinal tract model.

Then, simulated gastric fluid (SGF) (60 ml) and pepsin solution (40 mg pepsin [Sigma P6887] in 6.4 ml SGF) were added, and pH was corrected to 3.0 using HCl solution (Sigma H1758, for molecular biology), and 0.04 ml of 0.3 M/L $CaCl_2$ was added. After 10 min, another portion of pepsin (40 mg pepsin in 6.4 ml SGF) was added. The volume of all samples was adjusted to 80 ml using distilled water to enable quantitative analysis. Stirring was performed at 10 rpm for 1 hr. Samples (20 ml each) were collected using the microfiltration membrane mentioned above after 60 min (end of the gastric phase).

Then, 44 ml of simulated intestinal fluid (SIF) was added, followed by 1.224 g pancreatin (from porcine pancreas, Sigma P1625) and 7.33 g bile salts (Sigma 48305) (both suspended in 37.5 ml of SIF). The concentrations of pancreatin and the bile salts were calculated using the method described by Stewart et al. (2019). Then, 0.2 ml of 0.3 M/L $CaCl_2$ solution and 1 M/L NaOH were added to obtain pH 7.0, and the intestinal volume was completed to 161.7 mL using distilled water. Stirring was set at 10 rpm, and samples were taken after 4 hr. Samples (20 ml each) were collected using a microfiltration membrane as described above after 15, 90, and 120 min (end of the small intestine phase).

Simultaneously, a reagent (blank) sample containing the digestion fluid in DDI water was run in duplicate in the same manner. The Na results from the control sample (digestive fluids) were subtracted from those of each of the tested samples.

During the entire digestion (mouth, gastric, and intestinal phases), $CO_2$ (analytical grade, Linde Gas Poland, approximately 5–8 ml/min) was run individually through each digested sample using a syringe PTFE filter (0.4 $\mu$m).

### Calculations

For digestion, 100 g of cooked pasta (prepared in salted and unsalted water) was introduced into the oral phase along with 100 ml of salivary fluid. Using the Na content in g/kg (source data in Supplementary Table S1), we determined the amount of sodium (in mg) present in 100 g of pasta added to the digestion process. Knowing the amount of Na in 100 ml and recognising that the total volume in the oral phase was 200 ml (100 ml pasta + 100 ml digestive fluids), we calculated the amount of Na in this volume, and based on these calculations, determined the percentage release of Na at each stage of digestion.

### ICP-OES

Each digested sample, as well as the control sample (time zero), was prepared in four replicates. After drying at 65 °C for 24 hr, the samples were mineralised in a muffle furnace (550 °C, 12 hr, using hydrogen peroxide as the oxidising agent) as described elsewhere (Jachimowicz et al., 2021). Ash from mineralisation was dissolved in 10 ml of 1 M nitric acid ($HNO_3$). The sodium content was determined using inductively coupled plasma optical emission spectrometry ICP-OES with a 720-ES spectrometer 720-ES (Varian, Palo Alto, CA, USA) (Table 2). The LOD was calculated using the formula CL = 3 Sb/m, where "Sb" is the standard deviation of six replicate blank measurements and "m" is the slope value in the calibration curve (Pirsaheb et al., 2015). To draw the calibration curve, LCG standards were used to prepare mineral solutions with concentrations of 1, 2, 4, and 8 $\mu$g per 1 L. The accuracy of

**Table 1.** Characteristics of the studied pastas.

| | Formula composition of pasta | Cooking time, min (*al dente*) | Salt amount in raw product, g per kg | Na content in raw product, g per kg ± *SD* | Weight of the digested sample, g | Producer country |
|---|---|---|---|---|---|---|
| Pasta with seaweed | Durum wheat semolina, dried seaweed | 6 | 0.010 | 0.0283 ± 0.0013 | 100 | Poland |
| 4-egg pasta | Wheat flour, egg pulp, turmeric | 6 | 0.006 | 0.0048 ± 0.0002 | 100 | Poland |
| Rice noodles | Rice, corn starch, tapioca starch | 6 | 0.002 | 0.0001 ± 0.00001 | 10 | Poland |
| Durum wheat pasta | Durum wheat semolina | 8 | 0.001 | 0.0042 ± 0.0002 | 100 | Italy |
| Whole grain wheat-rye pasta | Whole grain wheat flour, whole grain rye flour | 5 | 0.002 | 0.0749 ± 0.0041 | 100 | Poland |

*Note.* Salt amount in raw product was declared by producer on the packaging. Na content in raw product was determined using inductively coupled plasma optical emission spectrometry.

**Table 2.** Data of triplicate certified reference materials analysis, and ICP-OES operating conditions.

| Parameters | Values |
|---|---|
| Certified reference material | LGC-7173 |
| Certified, mg $kg^{-1}$ | 1,180 |
| Observed, mg $kg^{-1}$ | 1,263 |
| Recovery rate, % | 107 |
| Certified reference material | NCS ZC 73009 |
| Certified, mg $kg^{-1}$ | 17.00 |
| Observed, mg $kg^{-1}$ | 15.91 |
| Recovery rate, % | 94 |
| ICP-OES operating conditions | |
| RF generator power | 1.2 kW |
| Plasma gas flow rate | 15.0 $dm^3$ $min^{-1}$ |
| Auxiliary gas flow rate | 2.25 $dm^3$ $min^{-1}$ |
| Nebulizer gas flow rate | 0.70 $dm^3$ $min^{-1}$ |
| Sample flow rate | 0.1 ml $min^{-1}$ |
| Replications | 4 |
| Read time | 15 s |
| Peristaltic pump rotation | 12 rpm |
| Parameters for the determination of Na | |
| Wavelength | 589.592 nm |
| LOD (limit of detection) | 0.25 mg $kg^{-1}$ |
| LOQ (limit of quantification) | 0.39 mg $kg^{-1}$ |

the results was validated using the 1 M $HNO_3$ and two reference samples: LGC 7173 Poultry Feed and NCS ZC 73009 Wheat. The rate of recovery of the analysed minerals ranged from 94% to 107%.

## Reagents and reference materials

The solutions were prepared using deionised water (Hydrolab Deioniser, Gdańsk, Poland) and ultrapure chemical reagents. Hydrogen peroxide (30% pure) and $HNO_3$ (65% ultra-pure) were purchased from POCH S.A. (Lublin, Poland). Standard solutions of ultra-scientific minerals (1,000 mg $L^{-1}$, 99.99% purity) were purchased from LGC Standards Sp. z.o.o. (Kiełpin, Poland). Certified reference material was used to check the quality.

(1) LGC 7173 Poultry feed (LGC Standards GmbH, Wesel, Germany) contained 1,180 mg Na per 1 kg.

(2) NCS ZC 73009 Wheat (National Institute of Standard and Technology, Gaithersburg, MD, USA) contained 17.0 mg Na per 1 kg.

## Statistical analysis

Routine statistical tests (average values, *SD*) and statistical differences (using Tukey's HSD test) with significant differences identified at $p < .05$, were performed using Statistica 13.1 (StatSoft, Poland). Pearson's correlation coefficient was also calculated between the sodium content in cooked pasta and the percentage of sodium absorption in the gastrointestinal tract under *in vitro* conditions.

# Results

The determined sodium content in raw pasta, after conversion into salt (salt = Na × 2.5), differs from the salt content in the product declared by the producers (Table 1). The amount of salt in pasta declared by manufacturers in all cases, except for rice pasta, was lower compared to the amount of salt calculated from the sodium content in the pasta. This shows discrepancies between analytical markings and information on the packaging.

The highest ($p < .05$) degree of sodium absorption was observed in the distal section of the small intestine, regardless of the pasta type or cooking method (with or without salt) (Table 3). In the distal section of the small intestine, sodium absorption ranged from 46.2% Na (pasta with seaweed, cooked with salt) to 67.7% Na (pasta with seaweed, cooked without salt). In other sections of the gastrointestinal tract, absorption varied depending on the type of pasta and the cooking conditions, with no significant trends identified. For pasta with seaweed, significant differences were observed between the products cooked with and without salt (Table 3). In the stomach and distal section of the small intestine, sodium bioavailability was higher in pasta cooked without salt (16.2% vs. 13.3%; $p = .033$ and 67.7% vs. 46.2%; $p = .021$), whereas, in the initial and middle sections of the small intestine, sodium bioavailability was higher for pasta cooked with salt (20.0% vs. 9.31%; $p = .002$ and 20.5% vs. 6.81%; $p = .008$). For 4-egg pasta, statistically significant differences in sodium absorption were observed only during digestion in the stomach, with higher absorption for pasta cooked without salt compared to that cooked with salt (16.2% vs. 13.6%; $p = .021$). No differences in sodium absorption were observed between 4-egg pasta cooked with or without salt during digestion in subsequent sections of the small intestine ($p > .05$). Statistically significant differences in sodium absorption from rice noodles cooked in water, with or without salt, were observed only in the middle section of the small intestine (20.7% vs. 23.0%; $p = .041$). No differences in sodium absorption were observed in rice noodles cooked with or without salt during digestion in the stomach or in the initial or distal sections of the small intestine ($p > .05$). For durum wheat pasta, significant differences were observed between the products cooked in unsalted and salted water at each digestion stage. In the stomach phase, as well as in the initial and middle sections of the small intestine, sodium bioavailability was higher for durum wheat pasta cooked in salted water compared to that cooked in unsalted water, with values of 17.5% vs. 12.4% ($p = .019$), 13.4% vs. 8.81% ($p = .020$), and 14.8% vs. 13.7% ($p = .048$), respectively. In contrast, Na bioavailability in the distal section of the small intestine was significantly higher in durum wheat pasta cooked in unsalted water (65.0% vs. 54.3%; $p = .037$). For whole grain wheat-rye pasta, significant differences were observed between the products cooked in unsalted and salted water during each phase of digestion. In the stomach phase, as well as in the initial section of the small intestine, Na bioavailability was higher for whole grain wheat-rye pasta cooked in salted water compared to that cooked in unsalted water, with values of 17.5% vs. 12.4% ($p = .019$), 12.5% vs. 6.57% ($p = .013$), and 19.0% vs. 10.1% ($p = .009$), respectively. In contrast, Na bioavailability was significantly higher in pasta cooked in unsalted water in the middle and distal sections of the small intestine, with values of 21.4% vs. 15.2% ($p = .023$) and 61.9% vs. 53.3% ($p = .036$), respectively.

Considering the quantitative values, statistically significant higher sodium absorption was confirmed for pasta cooked in salted water compared to that cooked in unsalted water for three types of pasta: pasta with seaweed (130.5 vs. 73.68 mg $kg^{-1}$; $p = .026$), 4-egg pasta (82.47 vs. 72.58 mg $kg^{-1}$; $p = .045$), and durum wheat pasta (120.4 vs. 80.83 mg $kg^{-1}$; $p = .009$), but not for rice noodles (130.5 vs. 126.5 mg $kg^{-1}$; $p = .059$) or whole grain wheat-rye pasta (104.2 vs. 105.6 mg $kg^{-1}$; $p = .071$) (Table 4). However, when considering percentage values, statistically significant differences in sodium absorption were confirmed between pasta cooked in salted and unsalted water for three types of pasta: pasta with seaweed (97.8% vs. 61.8%; $p = .030$), durum wheat pasta (90.46 vs. 82.85%; $p = .047$), and whole grain wheat-rye pasta (96.33 vs. 74.07%, $p = .020$) (Table 4). No statistically significant differences were observed in the degree of sodium absorption between pasta cooked in salted and unsalted water for the 4-egg pasta (99.72% vs. 94.75%; $p = .061$) and rice noodles (99.96% vs. 91.76%; $p = .064$). A strong positive correlation ($r = 0.871$) was found between the sodium content in the cooked pasta and its absorption rate in the gastrointestinal tract (Table 4).

## Discussion

In our study, we observed that the addition of salt to the water in which pasta is cooked, the type of pasta, and the digestion phase have a significant impact on sodium absorption. Jachimowicz et al. (2021) demonstrated that cooking pasta in salted water increased the sodium content by approximately 128% (when the pasta was rinsed after cooking) to 250% (when the pasta was not rinsed after cooking). Similar trends have been observed by other authors (Bianchi et al., 2019; Jambrec et al., 2015). An increase in the sodium content of cooked pasta leads to increased sodium absorption in the gastrointestinal tract. Our study showed that the amount of sodium absorbed in the gastrointestinal tract under *in vitro* conditions was positively correlated with the sodium content of cooked pasta. Therefore, to reduce sodium intake in the diet, it is advisable to avoid adding salt to water when cooking pasta. This is important because pasta is one of the most commonly consumed food products (Pinel et al., 2025). According to Winiarska-Mieczan et al. (2019), cereal products, including pasta, contribute as much as 21.74 g of sodium per month, covering almost half of the Na requirement for Poles.

In the present study, we observed greater sodium absorption from pasta cooked with salt during the gastric digestion phase (durum wheat pasta and whole wheat grain with rye pasta), the initial phase of the small intestine (pasta with seaweed,

**Table 3.** Comparison of Na absorption from pasta cooked in unsalted and salted water, %.

| | Pasta with seaweed | | | 4-egg pasta | | | Rice noodles | | | Durum wheat pasta | | | Whole grain wheat-rye pasta | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Without salt | With salt | *p* value | Without salt | With salt | *p* value | Without salt | With salt | *p* value | Without salt | With salt | *p* value | Without salt | With salt | *p* value |
| Stomach | $16.2^{bC} \pm 1.02$ | $13.3^{aA} \pm 0.65$ | .033 | $16.2^{bB} \pm 0.76$ | $13.6^{aA} \pm 0.47$ | .021 | $16.3^{B} \pm 0.73$ | $15.9^{B} \pm 0.44$ | .061 | $12.4^{aB} \pm 0.53$ | $17.5^{bB} \pm 0.44$ | .019 | $6.57^{aA} \pm 0.09$ | $12.5^{bA} \pm 0.31$ | .013 |
| Start of the small intestine | $9.31^{aB} \pm 0.44$ | $20.0^{bB} \pm 1.02$ | .002 | $12.8^{A} \pm 0.33$ | $13.4^{A} \pm 0.28$ | .059 | $13.9^{A} \pm 0.78$ | $13.4^{A} \pm 0.41$ | .065 | $8.81^{aA} \pm 0.23$ | $13.4^{bA} \pm 0.39$ | .020 | $10.1^{aB} \pm 0.30$ | $19.0^{bC} \pm 0.17$ | .009 |
| Middle of the small intestine | $6.81^{aA} \pm 0.51$ | $20.5^{bB} \pm 0.79$ | .008 | $17.6^{B} \pm 0.20$ | $18.3^{B} \pm 0.73$ | .060 | $20.7^{aC} \pm 0.29$ | $23.0^{bC} \pm 0.48$ | .041 | $13.7^{aB} \pm 0.19$ | $14.8^{bA} \pm 0.56$ | .048 | $21.4^{bC} \pm 0.11$ | $15.2^{aB} \pm 0.22$ | .023 |
| End of the small intestine | $67.7^{bD} \pm 2.23$ | $46.2^{aC} \pm 2.04$ | .021 | $53.4^{C} \pm 1.01$ | $54.7^{C} \pm 0.99$ | .058 | $49.1^{D} \pm 1.01$ | $47.7^{D} \pm 0.72$ | .052 | $65.0^{bC} \pm 0.84$ | $54.3^{aC} \pm 0.22$ | .037 | $61.9^{bD} \pm 0.92$ | $53.3^{aD} \pm 0.15$ | .036 |
| *p* value | .021 | .035 | | .039 | .018 | | .033 | .020 | | .041 | .030 | | .009 | .012 | |

*Note.* $^{a,b}$means with different superscripts in lines differ at $p < .05$ by Tukey's HSD test. $^{A–D}$means with different superscripts in columns differ at $p < .05$ by Tukey's HSD test; values are presented as $M \pm SD$.

**Table 4.** Na absorption in an *in vitro* model from pasta cooked in water without or with salt, and Pearson's correlation coefficient (between Na content in cooked pasta and its absorption rate *in vitro*).

| | Pasta with seaweed | | | 4-egg pasta | | | Rice noodles | | | Durum wheat pasta | | | Whole grain wheat-rye pasta | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Without salt | With salt | *p* value | Without salt | With salt | *p* value | Without salt | With salt | *p* value | Without salt | With salt | *p* value | Without salt | With salt | *p* value |
| Na content of cooked pasta, mg $kg^{-1}$ | $119.2^{a} \pm 6.02$ | $133.4^{b} \pm 8.14$ | .032 | $76.60 \pm 2.51$ | $82.70 \pm 3.05$ | .057 | $142.2^{b} \pm 6.38$ | $126.5^{a} \pm 5.60$ | .031 | $97.56\ ^{a} \pm 3.55$ | $133.1^{b} \pm 1.87$ | .022 | $140.7^{b} \pm 3.18$ | $109.6^{a} \pm 4.08$ | .008 |
| The amount of Na absorbed, mg $kg^{-1}$ | $73.68^{a} \pm 3.15$ | $130.5^{b} \pm 4.52$ | .026 | $72.58^{a} \pm 3.75$ | $82.47^{b} \pm 1.82$ | .045 | $130.5 \pm 7.02$ | $126.5 \pm 1.58$ | .059 | $80.83^{a} \pm 5.57$ | $120.4^{b} \pm 3.03$ | .009 | $104.2 \pm 2.31$ | $105.6 \pm 4.02$ | .071 |
| % of absorbed Na * | $61.80^{a} \pm 3.04$ | $97.79^{b} \pm 3.22$ | .030 | $94.75 \pm 4.17$ | $99.72 \pm 2.58$ | .061 | $91.76 \pm 3.45$ | $99.96 \pm 4.09$ | .064 | $82.85^{a} \pm 1.77$ | $90.46^{b} \pm 5.12$ | .047 | $74.07^{a} \pm 4.06$ | $96.33^{b} \pm 1.25$ | .020 |
| *r* | 0.871 | | | | | | | | | | | | | | |

*Note.* *Na content of cooked pasta was taken as 100%; *r*—Pearson correlation coefficient. $^{a,b}$means with different superscripts in lines differ at $p < .05$ by Tukey's HSD test; values are presented as $M \pm SD$.

durum wheat pasta, and whole wheat grain with rye pasta), and the middle phase of the small intestine (pasta with seaweed, durum wheat pasta, and rice noodles). In the final phase of the small intestine, greater sodium absorption was observed in pasta cooked without salt (pasta with seaweed, durum wheat pasta, and whole wheat grain with rye pasta). These results suggest that the addition of salt during pasta cooking and the phase of food digestion affects sodium absorption. For most (8 out of 14 statistically significant results, $p < .05$) pasta cooked with salt, considering the different phases of the gastrointestinal tract, significantly higher percentage values of sodium absorption were observed compared to pasta cooked without salt. This suggests that, in most cases, the addition of salt to boiling pasta increases Na absorption from the gastrointestinal tract. Excessive sodium absorption can lead to negative health consequences, such as a higher risk of cardiovascular diseases, hypertension, stroke, improper development of the skeletal system, and indirect effects on the incidence of obesity and stomach cancer (Mazzuca et al., 2024; Pashaei et al., 2022; Rysová & Šmídová, 2021).

The rate of food digestion and its location within the gastrointestinal tract are crucial for human health. Our research demonstrated that in all examined samples, the highest sodium absorption occurred in the distal section of the small intestine, regardless of the prior method of pasta preparation and its type. Sodium supplied by food is primarily absorbed in the distal part of the small intestine. To maintain sodium homeostasis, as much as 95% of the sodium ingested from food is excreted through the kidneys, 4.5% through the gastrointestinal tract, and 0.5% through the skin (Surma et al., 2020). The jejunum is the primary site for the absorption of water and electrolytes, and this process occurs to a minimal extent in the stomach and duodenum. We consume 5–15 g of NaCl daily, and the gastrointestinal tract secretes an extra 30 g. The small intestine absorbs approximately 75% of the Na that reaches it while simultaneously secreting approximately 2 L of sodium-containing fluid (Campbell, 2014).

The absorption of sodium ions occurs through various mechanisms depending on the section of the gastrointestinal tract (Jachimowicz-Rogowska & Winiarska-Mieczan, 2023). The regulation of Na metabolism involves many mechanisms, primarily the renin-angiotensin-aldosterone system, the reduction of sodium load reaching the *macula densa* in the distal convoluted tubule of the nephron, and the natriuretic peptide system and pressure-induced natriuresis (Stąpor et al., 2023; Surma et al., 2020). Excessive salt intake leads to a reduction in the number of *Lactobacillus murinus* bacteria, which reduces the quantity of indolic compounds, thereby stimulating the differentiation of T lymphocytes into Th17 cells. These lymphocytes secrete interleukin-17 (IL-17), which enhances sodium reabsorption in the intestines (Surma et al., 2020).

The initial sodium content in cooked pasta and the presence of components that can significantly affect the bioavailability of Na are important (Bianchi et al., 2019; Bustos et al., 2017). The bioavailability of mineral nutrients may be limited by the dietary fibre present in plant-based products (Adams et al., 2018). Although the literature on the impact of dietary fibre on sodium bioavailability is limited, making it difficult to determine whether dietary fibre affects Na bioavailability (Lakey-Beitia et al., 2021), our study found that significantly ($p < .05$) less sodium was absorbed from whole grain wheat-rye pasta than from rice or semolina pasta, although this was only observed when the pasta was cooked in unsalted water. A likely contributing factor is that in whole grain wheat-rye pasta cooked in salted water, the Na content increased by approximately 30% compared to pasta cooked in unsalted water, and we observed a positive correlation between the amount of sodium in the pasta and the amount absorbed in the gastrointestinal tract. Bianchi et al. (2019) hypothesised that sodium is absorbed to a lesser extent from whole grain products than from those made from semolina; however, this was not supported by their findings in relation to pasta. However, their research confirmed that Na retention depends on the salt concentration in the water used for cooking pasta. Mineral absorption is also limited by phenolic compounds, which are natural plant metabolites (Lakey-Beitia et al., 2021). In our study, sodium absorption was the lowest ($p < .05$) for pasta with seaweed compared to other types of pasta, but only when cooked in unsalted water. When cooked in salted water, the sodium bioavailability from this pasta increased by nearly 37% compared to that of the unsalted variant, reaching approximately 98%. In this case, pasta cooked in salted water contained 12% more Na than pasta cooked in unsalted water. Seaweeds are naturally low in sodium, although they are a rich source of salt (Notowidjojo et al., 2021; Rakhasiya et al., 2025). However, it is a low-sodium salt. Furthermore, the pasta was free from the added table salt, as indicated by the manufacturer's statement on packaging. In this case, similar to whole grain wheat-rye pasta, the absorption of sodium from the product was positively correlated with its sodium content. In our study, sodium absorption exceeded 90% in all pasta types cooked in salted water, further supporting this observation.

In a study published by Passannanti et al. (2017), a dynamic *in vitro* digestion model (Tiny-TIM) was developed to simulate digestion in 6-month-old infants. The main aim of the study was to understand the digestion of rice-based products. The model allowed for the assessment of the bioavailability of minerals, including sodium, after passing through a simulated gastrointestinal tract. It was shown that factors such as the food matrix (e.g., rice products) and physicochemical conditions (pH, residence time in individual parts of the gastrointestinal tract) significantly affect the amount of sodium available for absorption. The results emphasised the usefulness of such *in vitro* models in studying the absorption of nutrients without the need for human studies. In another study, the authors focused on the analysis of the effect of digestion duration on the activity of proteolytic enzymes (pepsin and pancreatic enzymes) in *in vitro* digestion models and on the consequences of this phenomenon for the assessment of the bioavailability of macronutrients, including sodium (Stewart et al., 2019). As it turned out, both proteolytic enzymes showed a significant decrease in activity over time during simulated digestion. Reduced enzyme activity can lead to incomplete digestion of nutrients, which in turn affects the assessment of their bioavailability. In the context of studies on sodium bioavailability, taking into account the decrease in enzyme activity is important for obtaining reliable results. There is a lack of studies on the absorption of sodium from the gastrointestinal tract from various types of food products using *in vitro* digestion models.

## Limitations

*In vitro* digestion models are an excellent screening tool for studying the bioavailability, degradation of ingredients, and stability of food in the gastrointestinal tract. They do not replace *in vivo* studies but are widely used and very useful in food research. Important limitations that should be taken into account in the analysis of results are lack of full compliance with physiological conditions *in vivo* (e.g., influence of the nervous, hormonal, immune systems on digestion); lack of gut microbiota; peristaltic movements in the intestines are difficult to reproduce; and *in vitro* models end at the intestinal level, so they do not take into account the absorption by enterocytes and the transport of compounds in the blood (Minekus et al., 2014).

## Conclusion and perspectives

Our research has shown that cooking in salted water has a significant impact on increasing sodium bioavailability in the gastrointestinal tract, and the percent of sodium absorption from pasta is positively correlated with the sodium content in the product, which in turn depends on the salt concentration in the cooking water. Statistically significant higher percent of sodium absorption was confirmed for pasta cooked in salted water compared to that cooked in unsalted water for three of five types of pasta: pasta with seaweed, durum wheat pasta, and whole grain wheat-rye pasta. This suggests that the recipe composition of the pasta is probably the most important, because it was the differentiating factor. Cooking time also requires consideration. In the perspective of further research, it would be worth checking the sodium absorption from pasta cooked for the same optimal time, regardless of the time suggested by pasta producers. We conclude that further research in this area is needed.

It should be noted that this is a preliminary study. Our team intends to expand it to include other food products to verify our findings for pasta. To date, there has been a paucity of research on the bioavailability of Na from pasta and other food products within the gastrointestinal tract. The lack of comprehensive data hinders in-depth analysis of this issue. Therefore, there is an urgent need for further research in this area, which would enhance our understanding of the relationship between the salt content of food products and sodium absorption. The discrepancies between sodium content in raw pasta and salt amount information on the packaging are also intriguing. This topic should be addressed in future studies.

The high dietary intake from the human diet in both developed and developing countries and the ongoing efforts to develop strategies aimed at reducing table salt consumption. Various forms of nutrition education that address the high absorption of salted products from the gastrointestinal tract are needed due to excessive salt consumption in the entire population, both adults and children.

## Supplementary material

Supplementary material is available at *International Journal of Food Science and Technology* online.

## Data availability

The data underlying this article are available in the article and in its online supplementary material.

## Author contributions

Karolina Jachimowicz-Rogowska (Conceptualisation, Writing—original draft), Anna Winiarska (Project administration, Writing—review & editing), Dominik Szwajgier (Writing—review & editing), and Ewa Baranowska-Wójcik (Data curation, Investigation, Methodology)

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## Conflicts of interest

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Table S1. Sodium content of cooked pasta

| Section of the digestive tract | Pasta with seaweed | | 4-egg spiral pasta | | Rice noodles | | Durum wheat pasta | | Whole grain wheat-rye pasta | |
|---|---|---|---|---|---|---|---|---|---|---|
| | without salt | with salt | without salt | with salt | without salt | with salt | without salt | with salt | without salt | with salt |
| | Na g/kg of cooked pasta | | | | | | | | | |
| | 0.12 | 0.13 | 0.08 | 0.08 | 0.14 | 0.13 | 0.1 | 0.13 | 0.14 | 0.11 |
| | Na g/kg of cooked pasta after digestion | | | | | | | | | |
| Stomach | 2.40 | 3.39 | 2.45 | 2.25 | 2.70 | 4.03 | 2.02 | 4.22 | 1.46 | 2.64 |
| Start of the small intestine | 1.38 | 5.08 | 1.94 | 2.22 | 2.29 | 3.40 | 1.43 | 3.23 | 2.25 | 4.03 |
| Middle of the small intestine | 1.01 | 5.21 | 2.67 | 3.03 | 3.42 | 5.84 | 2.23 | 3.55 | 4.76 | 3.22 |
| End of the small intestine | 10.04 | 11.75 | 8.10 | 9.05 | 8.12 | 12.12 | 10.55 | 13.06 | 13.75 | 11.30 |

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# Bread consumed in recommended portions does not provide excessive amounts of sodium and salt in children's diet

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**Bread is a common component of the human diet worldwide. Owing to its prevalence in the diet, it significantly contributes to meeting the daily recommended salt intake, and may even exceed it. The study aimed to determine whether bread is an important source of salt in children's diets. This was achieved through three analyses: (1) analysis of sodium (Na) and salt content in seven types of bread purchased in Poland, (2) assessment of whether the consumption of the recommended daily servings of bread exceeds the Adequate Intake (AI) of Na in children's diets, (3) estimation of the contribution of bread to salt intake in children's diets across four age groups: 1–3, 4–6, 7–9, and 10–12 years. The study showed the highest Na and salt content in rye bread and the lowest in spelt bread. The daily consumption of recommended bread in all age groups did not exceed the recommended daily salt intake. However, bread consumption often exceeds the recommended amount and bread is consumed along with other foods that provide significant amounts of salt. Additionally, other cereal products containing considerable amounts of salt frequently appear in children's diets. Effective nutrition education programs are needed to raise consumer awareness about the health impact of excessive salt consumption through bread, as well as legal regulations that require bread producers to reduce salt content during production to mitigate the risk of health complications.**

**Keywords** Bread, Salt, Sodium intake, Cereal products, Children's diet

Cereal products, including bread, play an important role in the daily diet. In the last several years, Poland has seen a significant decline in bread consumption, although it remains a widely consumed product (the majority of the population eats bread several times a day) and therefore should be of very high quality[1]. In Polish households, bread and rolls dominate cereal product consumption, with nearly 130 g per person per day, accounting for 21.9% of the energy consumed in an average diet[2]. The final quality of the product depends on the type and quality of the raw materials as well as the technological process applied[3,4]. According to a survey of adult Poles, the most commonly consumed types of bread were dark rye and light wheat bread, whereas the least consumed were semi-sweet and crisp bread[4].

The high proportion of bread in the daily diet, its commonness and high nutrition value indicates that it plays an important role from a nutritional perspective. Bread is one of the primary source of energy, nutrients, and bioactive compounds. It is also a source of mineral elements such as sodium (Na), magnesium, zinc, and vitamins: E and some vitamins from the B group[5]. Wholegrain products are a crucial source of dietary fibre, with beneficial effects related to lipid and carbohydrate metabolism as well as the regulation of digestive system function[6].

Bread is a commonly consumed product; therefore, its quality must be high. The final quality of the product depends on the type and quality of the raw materials as well as the technological process[3]. Each type of flour is characterised by different milling degrees and mineral contents. Bread baked from whole wheat or rye flour (i.e. type 1850, 2000) has a higher nutritional value, as it contains more total dietary fiber, vitamins and mineral salts present in the outer covering of the grains. Bread baked from low-grade flour (i.e. type 550, 750) has a lower nutritional value and is usually more caloric[7].

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Salt is an important technological additive that acts as a bread quality improver. The addition of small amounts (1–3% of all ingredients) during the dough preparation phase reduces amylase activity, makes starch less susceptible to amylase action, increases the starch gelatinisation temperature, improves the appearance of bread loaves, increases their volume, promotes browning of the crust, and makes it crispy, while the crumb becomes more delicate[8]. Salt affects gluten development and characteristics[9]. The presence of salt improves dough elasticity and mechanical processing[10]. Moreover, it inhibits the growth of harmful bacteria during dough fermentation[7]. It may also affect the shelf life of bread by influencing water activity[11]. Moreover, the use of salt in baking bread gives it a desirable, pleasant taste.

Higher salt content (> 1.8%) is permitted in rye bread[12]. This is related to the effect of salt on fermentation and the prevention of spoilage bacterial growth, which may be more prevalent in wholemeal flours. In contrast, the salt addition to wheat bread dough usually does not exceed 1.5%, whereas mixed bread often contains between 1.6 and 1.8% salt[12]. According to Rysová and Šmídová[10] the salt content in bakery products ranges from 0.9 to 1.7%. The use of high salt content by producers is determined by the need to provide adequate baking properties and enhance the flavour of bread[12].

Any reduction in salt content in bakery products, even if partial, should be gradual[13]. Reformulated products with lower salt contents must be acceptable in terms of sensory characteristics and must maintain an appropriate shelf life[10]. Currently, natural salt substitutes are available, allowing for a salty taste while simultaneously reducing the Na content. These include potassium chloride, magnesium chloride and calcium chloride[14]. A relatively new technique involves using larger salt crystals[15]. Substances that strongly enhance the salty flavour were also used, enabling a reduction in the salt dosage. These salt enhancers include amino acids, protein hydrolysates, nucleotides, yeast extracts, seaweed (nori and kelp), trehalose, glutamate, soy sauce, and lactate salts[10,16,17]. Spices and herbs such as garlic, lovage, and coriander enhance the perception of salty taste and have various antimicrobial properties that help preserve the shelf life of bread. The addition of herbs allows for a 50% reduction in salt content, while maintaining the same intensity of salty taste perception[18].

The European Food Safety Authority (EFSA) has determined that a daily sodium intake of 2000 mg (equivalent to 5 g of salt per day) is safe and adequate for the adult population in Europe[19]. The World Health Organization (WHO) recommends limiting salt intake to 5 g per day[20]. According to the Nutrition Standards for the population of Poland, the adequate intake (AI) of Na for adults is 1500 mg per day, similar to that in the USA, Canada, Germany, Austria, Switzerland, France, and Nordic countries[21]. For children, the values established for adults were extrapolated, considering the lower energy intake in different age groups (Table 1). The recommended maximum Na intake for adults (≥ 16 years old) should be adjusted downward, considering the energy requirements of children (2–15 years old) in comparison with those of adults[20]. These amounts refer to the total salt intake, including both the salt added during food preparation and the salt contained in processed food products such as bread. It should be noted that sodium AI is not an ideal level that needs to be reached, but it is maximum and we should consume less.

In practice, long-term consumption of salt above the recommended levels in adults adversely affects the cardiovascular system, increasing the risk of hypertension, heart disease, and stroke and indirectly influencing the incidence of stomach cancer[10,22]. The habit of eating salty foods, preference for choosing them, and eating habits established in childhood are reflected in adulthood. A preference for salty taste develops as a result of repeated exposure to salty foods. As infants become familiar with salty taste, they gradually begin to prefer it. Similar to the preference for sweet taste, children prefer higher concentrations of salt than adults[23]. Moreover, high salt intake during childhood can contribute to the development of various diseases, such as hypertension, in adulthood[24]. Excessive salt intake can adversely affect the proper development of bones in children. Obesity, hypertension, increased salt sensitivity, high consumption of sweet drinks, and elevated mortality and morbidity rates persisting into adulthood are the main consequences of increased salt intake during the first 1000 days of life[25]. Excessive salt intake by children also leads to excessive renal strain, as their kidneys are less developed than those of adults[21].

In high-income countries, excess sodium intake is mainly (75–80%) from processed foods and prepared meals, 10–15% comes from salt added during cooking or seasoning at the plate, and the remaining 5–10% occurs naturally in foods that are part of the diet, whereas the main source of salt in the diet of many low- and middle-income countries is salt added at home during cooking, seasoning, or preserving. Reducing sodium intake solely by avoiding the addition of salt to the plate and to cooking may not be particularly effective, because most dietary sodium comes from processed foods to which salt is added during manufacturing[23]. Owing to its prevalence in the diet, bread has been identified as the main factor influencing salt intake[22,26]. WHO[12] has proposed a 30%

| Age group | AI of Na (mg/d) | Salt (mg/d) |
|---|---|---|
| 1–3 | 750 | 1875 |
| 4–6 | 1000 | 2500 |
| 7–9 | 1200 | 3000 |
| 10–12 | 1300 | 3250 |

**Table 1**. The adequate intake (AI) of sodium (Na) for different age groups, along with the calculated daily recommended salt intake (salt = Na × 2.5) for children from various age groups, was based on WHO[20] and Rychlik et al.[21].

reduction in salt intake by 2025. It is considered the most cost-effective preventive measure for maintaining population health[23].

However, the requirement for Na should be addressed, as this element fulfils important functions in the body. The basic functions of Na include its role in water-electrolyte balance, acid–base equilibrium, and the functioning of the nervous system (conduction of nerve impulses) and muscles. Furthermore, Na is a component of hydrochloric acid in the stomach. The effects of Na deficiency include weakness, headache, nausea, vomiting, loss of appetite, and disorientation[21,27].

Although dietary tendencies vary around the world, excessive Na intake from cereal products to which salt is added at the production stage affects most of the population, including unfortunately children. Bread is consumed by almost the entire population from an early age, excluding people on special diets or with food allergies, therefore we believe that our results can be applied not only to the population of children living in Poland, but also in other regions of Europe and the world[13,20,28].

In the context of children's nutrition, the issue of the harmfulness of excess sugar is often raised. The topic of excess salt is omitted. In the near future, this will probably become an increasing problem and will attract the attention of researchers. This was the main reason why we decided to discuss this issue in this paper.

This study aimed to determine whether bread is an important source of salt in children's diets. This was achieved through three analyses: (1) analysis of Na and salt content in seven types of bread, (2) assessment of whether the consumption of the recommended daily servings of bread exceeded the AI of Na in children's diets, and (3) estimation of the contribution of bread to salt intake in children's diets.

## Results

### The content of Na and salt in bread and flour

Table 2 shows the average Na and salt contents in bread, expressed per 1000 g and per slice of bread (30 g). On average, the bread contained 7258.6 mg Na/1000 g and 217.8 mg Na/30 g. Bread analysis showed the highest Na and salt content in rye bread (averaging 8333 mg Na/1000 g and 20,833 mg salt/1000 g; 250 mg Na/30 g and 625 mg salt/30 g), and the lowest in spelt bread (averaging 6066 mg Na/1000 g and 15,165 mg salt/1000 g; 182 mg Na/30 g and 455 mg salt/30 g). Statistically significant differences ($p < 0.0001$, Tukey's HSD test) in Na and salt content in different types of bread are presented in Table 2. The differences shown between Na and salt values per 1000 g and per 30 g are the same because salt equivalent = Na × 2.5.

The salt and Na contents in bread can be represented as follows: rye bread > wheat-rye bread > wheat bread > whole grain toast bread > graham bread > wheat toast bread > spelt bread.

The average Na values ranged from 1.42 to 3.61 mg/1000 g. Flour analysis showed the highest Na content in spelt flour (3.6 mg/1000 g) and the lowest in rye flour (1.4 mg/1000 g). The Na content in the flours can be represented as follows: spelt flour > wheat flour type 750 > whole grain wheat flour type 2000 > rye flour. When comparing the Na content in a natural product derived from cereal grains (such as flour) to the Na content in bread (to which salt is added during dough preparation), differences were observed. The Na content in wheat bread flour (type 750) is 2.56 mg/1000 g, while in wheat bread it is 7598 mg/1000 g. The Na content in wholegrain wheat flour (type 2000) is 1.75 mg/1000 g, while in wholegrain toast bread, it is 7465 mg/1000 g. The Na content in rye flour is 1.42 mg/1000 g, while in rye bread it is 8333 mg/1000 g. The Na content in spelt flour is 3.61 mg/1000 g, while in spelt bread it is 6066 mg/1000 g. Flour was not a significant source of Na in the bread. The high Na content was due to the salt added to the bread during the production stage.

### Bread as a source of Na and salt

To determine daily Na intake from bread, recommendations for bread consumption for different age groups were referenced (Table 3).

| | | mg per 1000 g | | mg per 30 g | |
|---|---|---|---|---|---|
| Type of bread | n | Na | Salt | Na | Salt |
| Wheat bread | 10 | 7598[ac] | 18995[ac] | 228[ac] | 570[ac] |
| Rye bread | 10 | 8333[a] | 20833[a] | 250[a] | 625[a] |
| Wheat-rye bread | 10 | 8099[ab] | 20247[ab] | 243[ab] | 607.5[ab] |
| Wheat toast bread | 10 | 6116[d] | 15290[d] | 183.5[d] | 458.8[d] |
| Whole grain toast bread | 10 | 7465[bc] | 18662[bc] | 224[bc] | 560[bc] |
| Graham bread | 10 | 7133[c] | 17832[c] | 214[c] | 535[c] |
| Spelt bread | 10 | 6066[d] | 15165[d] | 182[d] | 455[d] |
| Mean value | 70 | 7258.6 | 18,146.2 | 217.8 | 544.5 |
| SD | | 891 | 2227 | 26.7 | 66.8 |
| SEM | | 336.8 | 841.7 | 10.1 | 25.2 |

**Table 2.** The mean content of Na and salt in mg per 1000 g and per 30 g (1 slice) of fresh product in the selected bread. Results are presented as averages of 2 replications; salt = Na × 2.5. *SD* standard deviation, *SEM* standard error of the means. [a,b,c,d]Means with different superscripts in columns differ at $p < 0.0001$ by Tukey's HSD test.

| Age group | Bread serving/day | Representation | Source |
|---|---|---|---|
| 1–3 | 20 g | Recommendations, model food ration | [29] |
| 4–6 | 30–35 g (on average 32.5 g) | Recommendations, sample diets | [30] |
| 7–9 | 40–50 g (on average 45 g) | | |
| 10–12 | 80 g | | |

**Table 3**. Recommended daily bread serving for children.

| Na intake from the recommended daily bread serving (mg) | | | | | The ratio of Na intake from the recommended daily bread serving to daily AI of Na (%) | | | |
|---|---|---|---|---|---|---|---|---|
| Age group | 1–3 | 4–6 | 7–9 | 10–12 | 1–3 | 4–6 | 7–9 | 10–12 |
| Bread serving (g)/day | 20 | 32.5 | 45 | 80 | | | | |
| AI of Na (mg) | | | | | 750 | 1000 | 1200 | 1300 |
| Wheat bread | 151.9$^{ac}$ | 246.8$^{ac}$ | 341.8$^{ac}$ | 607.6$^{ac}$ | 20.3$^{ac}$ | 24.7$^{ac}$ | 28.5$^{ac}$ | 46.7$^{ac}$ |
| Rye bread | 166.6$^{a}$ | 270.8$^{a}$ | 374.9$^{a}$ | 666.6$^{a}$ | 22.2$^{a}$ | 27.1$^{a}$ | 31.2$^{a}$ | 51.3$^{a}$ |
| Wheat-rye bread | 161.9$^{ab}$ | 263.2$^{ab}$ | 364.4$^{ab}$ | 647.8$^{ab}$ | 21.6$^{ab}$ | 26.3$^{ab}$ | 30.4$^{ab}$ | 49.8$^{ab}$ |
| Wheat toast bread | 122.3$^{d}$ | 198.7$^{d}$ | 275.1$^{d}$ | 489.0$^{d}$ | 16.3$^{d}$ | 19.9$^{d}$ | 23.0$^{d}$ | 37.6$^{d}$ |
| Whole grain toast bread | 149.3$^{bc}$ | 242.5$^{bc}$ | 335.8$^{bc}$ | 597.0$^{bc}$ | 19.9$^{bc}$ | 24.3$^{bc}$ | 28.0$^{bc}$ | 45.9$^{bc}$ |
| Graham bread | 142.6$^{c}$ | 231.8$^{c}$ | 320.9$^{c}$ | 570.5$^{c}$ | 19.0$^{c}$ | 23.2$^{c}$ | 26.7$^{c}$ | 43.9$^{c}$ |
| Spelled bread | 121.2$^{d}$ | 197.0$^{d}$ | 272.8$^{d}$ | 485.0$^{d}$ | 16.2$^{d}$ | 19.7$^{d}$ | 22.7$^{d}$ | 37.3$^{d}$ |
| Average | 145.1 | 235.8 | 326.5 | 580.5 | 19.2 | 23.6 | 27.2 | 44.6 |

**Table 4**. The Na intake from the recommended daily bread serving (mg) and the ratio of Na intake from the recommended daily bread serving to daily AI of Na (%). $^{a,b,c,d}$Means with different superscripts in columns differ at $p < 0.0001$ by Tukey's HSD test; recommended daily bread serving for children aged 1–3 came from Weker and Barańska[29] and for children aged 4–6, 7–9, and 10–12 came from Weker[30].

The daily intake of the recommended bread serving in all age groups did not exceed the adequate daily intake of Na (Table 4). It can be considered that by consuming the recommended (typical) bread portion throughout the day, the Na limit is not exceeded. Regardless of age group, the most popular sources of Na and salt were rye bread > wheat-rye bread > wheat bread > whole grain toast bread > graham bread > wheat toast bread > spelt bread. The average Na intake from a bread portion was as follows: 10–12 years (44.6% AI) > 7–9 years (27.2% AI) > 4–6 years (19.7% AI) > 1–3 years (16.2% AI). These values depend on the bread-serving size consumed by children. Statistically significant differences ($p < 0.0001$, Tukey HSD test) in Na and salt intake in relation to the recommended portion of bread for the age groups are presented in Table 4. Only the percentage of daily requirement that each bread provides changes, and the relationships between the breads are the same in each age group.

## The contribution of bread to Na intake in children's diets compared to other cereal products

Based on the results of our research and the information available in the literature regarding the salt content of cereal products, their contribution to salt intake in children's diets was estimated. The coverage of the recommended daily salt intake for different age groups of children was calculated individually for each product (pasta, corn crisps, crackers, milk slices, rice and corn waffles, sweet breakfast cereals, and flatbreads).

Figure 1 shows the contribution of cereal products to the daily recommended salt intake for children of different age groups. In each age group, the highest values were recorded for bread (19.2–44.6% of the daily recommended salt intake) and flatbreads (41.1–71.3%)—a type of flatbread baked from flour, consumed with various toppings, popular in European and Middle Eastern cuisines. Products such as corn crisps (12.0–20.8%) and crackers (14.6–25.3%), commonly consumed by younger and older children, respectively, also significantly contribute to the daily recommended salt intake across all age groups. In contrast, pasta, rice and corn waffles, consumed according to the established portion, did not significantly contribute to excessive salt intake in all age groups, as their share in the daily recommended salt intake was marginal (1.2–2.7%). For children aged 1–3 and 4–6, the top contributors of cereal products to meeting the daily recommended salt intake were flatbreads and the bottom was pasta; for children aged 7–9 the top contributors was flatbreads and the bottom was rice and corn waffles; and for children aged 10–12 the top contributor was bread and the bottom were sweet breakfast cereals = rice and corn waffles = pasta (Fig. 1).

Bread serving size was determined based on Weker and Barańska[29] and Weker[30] (Table 2); Pasta serving size was determined based on Jachimowicz et al.[1] (children aged 1–3 years 50 g, children aged 4–6 years 60 g, children aged 7–9 years 100 g, children aged 10–12 years 100 g); The serving size of breakfast cereals with milk was determined based on Winiarska-Mieczan et al.[31] (30 g cereals + 125 ml milk); The milk slices serving size was determined based on Jachimowicz-Rogowska et al.[32] (31.7 g); The serving sizes of corn crisps (30 g),

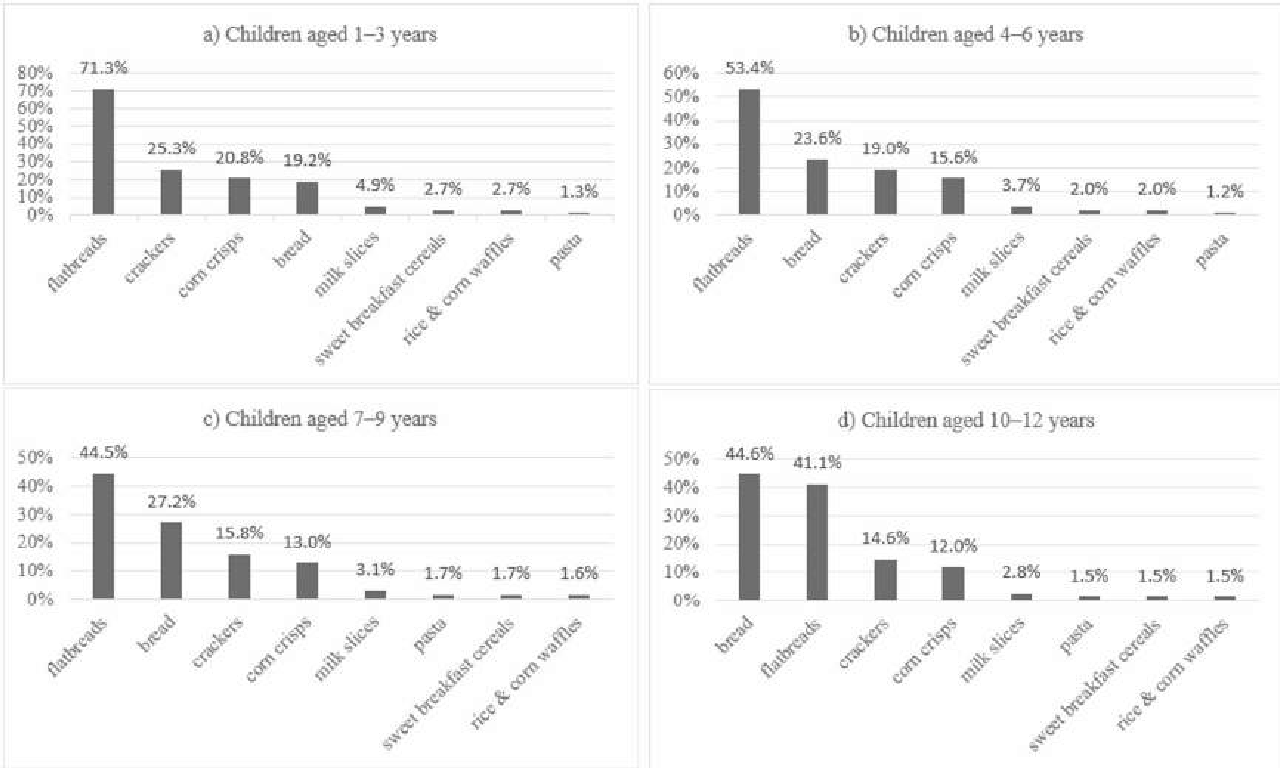


**Fig. 1**. Contribution of cereal products to the daily recommended salt intake for different age groups of children (%).

| Product | Amount of salt (g/1000 g) | References |
|---|---|---|
| Bread | 15.2–208.3 | Own research |
| Pasta | 0–0.5 | 1 |
| Milk slices | 0.08–4.8 | 32 |
| Sweet breakfast cereals | 0.62–1.78 | 31 |
| Corn crisps | 13.1 ± 0.00* | 33 |
| Crackers | 15.0–22.5 | 34 |
| Rice and corn waffles | 3.0–10.0 | 34 |
| Flatbreads | 15.020.0 | 34 |

**Table 5**. Data on salt content (min–max; g/1000 g) in bread and other cereal products. *No information was provided on the minimum and maximum values.

crackers (25 g), rice and corn waffles (10 g) and flatbreads (80 g) were determined based on commonly available food labels and the producers' recommendations on product packaging.

Table 5 shows the salt content (minimum and maximum values in grams per 1000 g) of the bread and other cereal products. Focusing on the salt content, significant variability was observed both between and within the analysed cereal products. Products with the highest salt content were bread (minimum–maximum: 15.2–208.3 g/1000 g), crackers (15.0–22.5 g/1000 g), and flatbreads (15.0–20.0 g/1000 g), while pasta had the lowest salt content (0–0.5 g/1000 g). The salt content in grams per 1000 g of cereal products can be represented as bread > crackers > flatbreads > corn crisps > rice and corn waffles > milk slices > sweet breakfast cereals > pasta. This indicates that bread, compared with other cereal products, contains the highest amount of salt per 1000 g.

## Discussion

The different grain groups consumed by children and adolescents contribute to the nutritional value of the diet and should be promoted as part of a healthy diet. Breads, rolls, and tortillas accounted for 6.6% of total energy in the daily diet of American children and adolescents[35]. According to Weker and Barańska, a child should eat bread and cereal products made from whole grains every day[29]. Bread was one of the three most frequently chosen food products by high school students. However, both girls and boys preferred bread made from processed (white) flour over whole wheat flour products[36]. In the study by Wołowski and Jankowska, more than half of junior high school students did not eat whole grain bread[37]. Children aged 2–18 years most often chose bread from the range of cereal products, but most of them ate whole grain bread only a few times a week (40%) or did not eat it at all (9%)[38]. More than half (55%) of preschool children also do not eat wholemeal bread, and 15% get it several times a week[39]. Wholemeal bread is a better source of fiber, B vitamins, zinc and magnesium than white bread, which is why children should choose it[38].

## The content of Na and salt in bread and flour—a comparison of the results obtained in own research with those presented by other authors

The study by Martins et al. analysed the mineral content in wheat bread and wheat bread with additives (fibre-enriched extracts, orange peel, pomegranate peel and interior membranes, and spent yeast)[40]. The Na content in wheat bread (3482 ± 135 mg/1000 g) and wheat bread with additives (3411 ± 7–3690 ± 127 mg/1000 g) from this study was lower than in our own study. Odunlade et al. reported significantly lower results than those of our study[41]. The Na content in white bread was 159 ± 0.2 mg/1000 g, whereas in white bread with 1–3% green leafy vegetable powder, it ranged from 182 ± 0.2 to 271 ± 0.3 mg/1000 g.

In a study by Carocho et al. rye bread produced in Portugal contained less Na (260 ± 10 mg/1000 g) than rye bread in our own study[42]. Wheat and rye bread from Maputo, Mozambique, also had lower Na contents, at 4191 ± 588 and 3898 ± 1212 mg/1000 g, respectively[43].

The rye bread in the study by Litwinek et al. had a slightly lower Na content (7906 ± 72–8153 ± 484 mg/1000 g) than the rye bread in our study[44]. The graham bread in the study by the cited authors also contained lower Na levels (6369 ± 180–6509 ± 19 mg/1000 g) than the graham bread analysed by our research group. On the other hand, the spelt bread in the study by the cited authors contained more Na (6378 ± 149–6598 ± 47 mg/1000 g) than the spelt bread in our study.

In our study, rye bread was found to have the highest salt content among all types of bread. In the study by Bazarnik and Dybkowska, the highest salt content was found in wheat baguettes (3.01%), whereas the lowest was in pastry (0.93%). The salt content of white toasted bread from various manufacturers was similar, averaging 1.33%[45]. Comparing this amount to the analysis conducted in our study, white toast bread contained lower amounts of salt (approximately 0.6%).

Salt is the main source of Na in bread. Bakery products account for up to 30% of the daily salt intake[46]. In contrast to the added salt, the flour used for bread baking provided only small amounts of Na. The ash content in the flours analysed by Ivanova et al. was the highest in oat flour at 5.0%, followed by spelt at 2.6%, barley at 2.0%, rye at 1.75%, wheat-rye at 1.23%, and wheat flour at 0.5%[47]. The ash content in the flour is correlated with the mineral content, including Na, derived from the seed husk. Wang et al. evaluated the content of minerals, including Na, in the various types of wheat flour[48]. Whole grain spelt flour contained 5400 ± 300 mg/1000 g Na, whole grain wheat flour contained 6500 ± 200 mg/1000 g Na, and wheat flour contained 2000 ± 100 mg/1000 g Na. All flours contained less Na than those in our study.

The differences between the results of our research and those of other authors may be due to national regulations (limits for added salt in bread products), food additives, and different bread recipes used in bakeries in Poland and in other regions of the world (e.g. Nigeria, Portugal, Mozambique). Soil composition, fertiliser use, and geographical factors (country of origin—e.g. USA, Bulgaria, United Kingdom, Germany) may also influence the mineral content, including Na, in grains[40–49].

## Bread as a source of salt in children's diet

Adults need to remember that the addition of salt to dishes served to young children should be as minimal as possible and that the products in their diet should be as minimally processed as possible and contain the lowest amount of salt[24]. Children and adults consume excessive amounts of salt, which directly affects their health[2].

The essential role of bread in supplying salt to the diet is important. Laskowski et al. found that bread accounted for 18% of the total Na intake in the Polish population[2]. Data are also not favourable for the British population, for whom cereal products accounted for 33% of the total Na intake, of which 17% was from bread[50], while in the USA, more than 50% of Na is derived from baked goods (bread and rolls)[51]. In studies on children's eating habits, bread often appears as one of the most commonly consumed products, contributing significantly to excessive salt intake[52,53]. In most cases, the salt intake in the studied populations of children is above the recommended levels[53–55]. It should be noted that children do not adhere to the salt intake recommendations. The main dietary source of salt is processed foods enriched with salt during processing[56]. Among them, bread is the principal source of salt, both due to its salt content per 100 g of product and the serving size consumed[52,57]. Besides bread and cereal products, other sources of salt include processed meat products (such as smoked products, sausages, hot dogs, cold cuts, and canned meats), dairy products (mainly rennet cheeses and sandwich cheese spreads), and canned vegetables, which are often consumed with bread[58,59]. This means that one meal can provide significant amounts of salt from various sources simultaneously. These products appear to be the main global sources of salt and should be included in efforts to reduce salt intake. Although, regional patterns have been observed regarding the dietary sources of salt—high-income countries typically consume most their salt from packaged and processed foods, while low and middle-income countries consume most salt from discretionary or added salt[28].

Setting maximum sodium limits of packaged foods (front-of-pack labelling) including bread is a useful strategy used in many countries. These sodium reduction policies are often voluntary, i.e. Australia and New Zeland, France (in 14% of WHO Member States) but very few are mandatory, i.e. Sri Lanka, Chile (in 6% of WHO Member States). Most of them are endorsement logo, followed by multiple traffic light system, proportion of daily intake, summary indicator or warning sign. In Poland front-of-pack labelling is voluntary, implemented as endorsement logo[60].

As mentioned previously, the addition of salt has a technological purpose in the bread-making process and may be necessary. But in the study by Gusmao et al.[61], reducing the addition of salt to bread dough from 1.2 to 0.6% or even 0.3% had no significant effect on the rheological and physical properties of bread. This means that the salt content reduced by a factor of two or even four does not significantly reduce the elasticity of bread dough. However, it is the gradual reduction of salt addition to bread that will have the least impact on consumer perception[62]. In developed countries, excessive salt intake is a major risk factor for hypertension and should encourage producers to reduce the amount of salt in their products for example by reformulating the recipes or using salt substitutes[23,50]. According to Goiana-da-Silva et al. in Portugal, reducing the salt content in bread from 1.4 to 1.0% would decrease daily salt intake by 3.6 tons per day, potentially preventing an estimated 286 deaths annually[63].

Both children and adults are exposed to excessive amounts of salt provided by bread. As long as bread is consumed according to the dietary recommendations for specific age groups, it does not exceed these limits. However, according to current reports, both children and adults consume significant amounts of bread, which contributes most significantly to exceeding the recommended dietary salt levels. Bread contains a relatively low level of added salt (on average 2% of all ingredients), but society consumes significant amounts of baked goods, which consequently accounts for 35–50% of salt intake[17,51,61,64]. Therefore, there is a need to reduce the addition of salt to bread during production, which could help reduce overall salt intake and decrease the risk of health complications[28]. A meta-analysis by Jaenke et al. showed that salt in bread could be reduced by up to 37% without decreasing consumer acceptability[65].

Considering only the salt content in the bread from our study, it can be stated that the best choice is spelt bread, which has the lowest salt content, whereas the worst option is rye bread, which has the highest salt content. In contrast, wholegrain breads, including rye bread, are made from flour that contains all parts of the grain: bran, germ, and endosperm. They are nutritionally superior to refined grains, which are stripped of bran and germ, leading to the loss of dietary fibre, vitamins, and minerals[66]. It should also be noted that consuming only low-salt bread but in excessive amounts, can still lead to excessive dietary intake of salt. Therefore, it is recommended to consume a variety of bread types, preferably in the specified recommended daily portion, to avoid excessive salt intake while supplying many other minerals (potassium, magnesium, copper, manganese, iron and zinc) from bread[67]. According to Winiarska-Mieczan et al. bread in the daily diet of Poles provides more than 90% of the minerals consumed in cereal products[57].

It should be highlighted that bread made from wholemeal flour contains more dietary fibre and offers many health benefits[68]. However, considering that fibre reduces the energy value of the diet and affects the conversion of nutrients (it reduces the absorption of minerals and fat-soluble vitamins), its excess is not recommended in the diets of infants and young children, malnourished individuals, and those in recovery[21]. It is recommended that the diets of older children include a variety of bread types, both whole grain and flour with a low milling degree[69]. In many Western countries, dietary fibre intake is lower than recommended because of insufficient consumption of whole grain products, fruits, and vegetables[70]. Consuming a variety of fibre-containing products is essential for digestive health, particularly for preventing constipation in children[71]. Nevertheless, low consumption of wholemeal bread is observed across various age groups, including children, adolescents, and adults[36,38,39,69].

## The contribution of bread as a source of salt in children's diet

Bread is an indispensable source of salt in children's diets. However, other cereal products that are commonly included in the diet also contribute to increased salt intake. One serving of bread corresponds to 19.2% of the recommended daily salt intake in the diet of children aged 1–3 years, 23.6% in the diet of children aged 4–6 years, 27.2% in the diet of children aged 7–9 years, and 44.6% in the diet of children aged 10–12 years. The high salt content in cereal products commonly consumed by children on a daily basis means that they can contribute significant amounts of salt from various sources simultaneously, including breakfast cereals (1.5–2.7% of the recommended daily intake), pasta eaten for lunch (1.2–1.7%), or snacks such as milk slices (2.8–4.9%), corn crisps (12.1–20.8%), crackers (14.6–25.3%), rice and corn waffles (1.5–2.7%), and flatbreads (41.1–71.3%) (see Supplementary Table S1 online). Breads, rolls and tortillas provided 7.7% of sodium in the American diet of children and adolescents daily[35]. Daily sodium intake from bread was approximately 6% and from processed cereals was approximately 7% in a study of 10–12 year old children from the Greek population[72].

## Perspectives

It is necessary to regularly examine other cereal products in context of salt content, not only bread. Children, for example, willingly eat sweet cereal products (bars, cookies, wafers etc.) but this food group also contains hidden salt. It is necessary to conduct comprehensive awareness-raising and preventive activities, e.g. media campaignes, because we get used to the taste of salty and we forget about its harmfulness[23].

There is a need for more research on Na and salt content in bread consumed by different age groups of the population, including children. Such studies could help to raise public awareness and highlight the issue of excessive salt intake and its impact on health. This is particularly important for children, as excessive sugar intake is more commonly observed in this consumer group, whereas salt consumption is primarily associated with adults.

Given the excessive salt intake in the populations of Poland and other countries, effective strategies should be designed to raise consumer awareness and reduce salt usage by producers of the most common foodstuffs, especially bread. It is also necessary to pay attention to the ingredients of purchased products—reading food labels and providing nutrition education in schools—as well as conducting informational campaigns in the media.

### Limitations of the study

The limitations are: (1) only bread purchased in Poland was tested but the problem is global; (2) only wheat and rye breads were tested; (3) without international cooperation in this field it will be difficult to implement effective global recommendations because salt is cheap, widely available, recipes are developed, people are used to a certain taste and appearance of bread; (4) the study does not take into account whether children actually eat as much bread as the recommendations for individual age groups indicate, but what would happen if they eat in accordance with the recommendations; (5) developing new recipes is cost-incuring; and (6) use of additives other than salt can increase the price of bread.

## Conclusions

In summary, this study showed that the final Na content in bread was significantly influenced by the addition of salt during bread production, not the sodium content in the flour. Spelt bread had the lowest salt content, whereas rye bread had the highest salt content. This may be due to the fact that a higher salt addition is allowed during rye bread production. Moreover, study shows that sodium content varies across different bread and flour subtypes.

The contribution of bread to salt intake in children's diets is high because of large portions and high sodium content, but other sources of salt from processed foods should also be considered. Cereal products such as breakfast cereals, pasta, sweet and salty snacks that are popular with children can contribute to exceeding established salt limits.

Daily consumption of the recommended bread servings in all age groups of children did not exceed the daily recommended salt intake; however, children often exceeded the recommended bread consumption. It should be noted that cereal products containing significant amounts of salt, when consumed in larger quantities, can contribute to a substantial increase in salt intake and exceed the recommended limits. Therefore, bread is an important source of salt in children diet.

## Methods

The protocol is exempt from Institutional Review Board approval.

### Study material

Seven types of bread (wheat, rye, wheat-rye, wheat toast, whole grain toast, graham, spelt) in 10 samples of each type and four types of bread flour (wheat type 750, whole grain wheat type 2000, rye, spelt) in 10 samples of each type were analysed. These types of breads were chosen because they are the most popular and the most frequently purchased breads in Poland[5]. The products were purchased in January 2023 in grocery stores in Lublin (eastern Poland). Samples were purchased from different stores to increase the diversity of analyzed products. All grocery stores selling bread and flour in the city of Lublin were taken into account, without limitations. All products were ahead of their use-by dates. On the day of purchase, 3 g (to one decimal place) of each bread and flour sample was weighed. The samples of bread included both breadcrumbs and crust cut from a slice with a thickness of two centimetres. Labelled data on bread composition were recorded.

### Contribution of bread and flour to Na intake in children's diets

The average Na content in the analysed products (bread and flour) was calculated by taking into account two replications for each determination in every sample. The serving of bread was considered to be 30 g, the average size of a slice, as the equivalent of the minimum consumed bread portion. The intake of Na in bread was compared against AI for Na intake in children[21].

### Chemical analyses

Prepared bread samples were placed in a dryer at 65 °C for 24 h. Each bread sample was ground separately in an electric grinder equipped with plastic blades. After manually mixing the material from each sample, 3 g was weighed in two replicates. The samples were mineralised in a muffle furnace at 550 °C for 12 h (antioxidant: hydrogen peroxide), as described previously[73]. The ash obtained from the mineralisation was dissolved in 10 ml 1 M $HNO_3$[74]. The Na content was assayed by inductively coupled plasma-optical emission spectrometry (ICP-OES) using a 720-ES spectrometer (Varian, Palo Alto, CA, USA). ICP-OES operating conditions: RF generator power—1.2 kW; plasma gas flow rate—15.0 $dm^3\ min^{-1}$; auxiliary gas flow rate—2.25 $dm^3\ min^{-1}$; nebulizer gas flow rate—0.70 $dm^3\ min^{-1}$; sample flow rate—0.1 ml $min^{-1}$; replications—4; reading time—15 s; peristaltic pump rotation—12 rpm Assay parameters:

Na: wavelength 589.592 nm, LOD 0.25 mg $kg^{-1}$, LOQ 0.39 mg $kg^{-1}$;

Certified reference material (CRM) was used to check the quality.

(1) NCS ZC 73,009 Wheat (National Institute of Standard and Technology, Gaithersburg, MD, USA) contained 17.0 mg Na per 1 kg;
(2) LGC 7173 Poultry feed (LGC Standards GmbH, Wesel, Germany) contained 1180 mg of Na per 1 kg.

The LOD was calculated using the formula CL = 3 Sb/m, where "Sb" is the standard deviation of six replicate blank measurements and "m" is the slope value in the calibration curve[75].

To draw the calibration curve, LCG standards were used to prepare mineral solutions with concentrations of 1, 2, 4, and 8 µg Na per 1 L. The correctness of the results was validated by means of the 1 M $HNO_3$ and CRM. The Na recovery rate was 94%.

### Reagents and reference materials

The solutions were prepared using deionised water (deioniser Hydrolab, Gdańsk, Poland) and ultrapure chemical reagents. Hydrogen peroxide (30% pure) and nitric acid (65% ultra-pure) were purchased from POCH S.A. (Lublin, Poland). Standard solutions of Ultra Scientific sodium (1000 mg $L^{-1}$, 99.99% purity) were purchased from LGC Standards Sp. z o.o. (Kiełpin, Poland).

### Calculations and statistical analysis

1. Based on the mean content of Na in bakery goods and flours, the Na content was calculated per 1 slice (30 g for bread), per 1000 g of each product, and per 1 portion according to the recommendation (Table 2). The specified portions of bread were based on Polish dietary guidelines for children[29,30].
2. The ratio of Na intake from the recommended daily bread serving to daily AI of Na (%) were calculated using the following formula:

$$\frac{\text{Na content in a serving of bread recommended for consumption per day (mg)}}{\text{AI of Na (mg)}} \times 100$$

3. According to the Nutrition Standards for the Population of Poland, the AI for Na is 750 mg per day for children aged 1–3, 1000 mg per day for children aged 4–6, 1200 mg per day for children aged 7–9, and 1300 mg per day for children aged 10–12[21]. Na intake from bread was compared with these standards.

The salt equivalent was determined as follows:

$$\text{NaCl equivalent} = \text{Na} \times 2.5$$

4. The Na contents (mg per 1000 g) of flour and bread were compared. Wheat bread and wheat toast bread were assigned wheat flour type 750; rye bread was assigned rye flour; wholegrain toast bread and graham bread were assigned wholegrain wheat flour type 2000; while spelt bread was assigned spelt flour.

When calculating the Na content of bread, the Na derived from the flour was subtracted to demonstrate how much Na came from the added salt during the bread production stage. At the same time, this allowed us to highlight how much Na could be saved by reducing the amount of salt added to the bread.

5. The contribution of bread to salt intake in the children's diet was calculated based on: (1) the salt content in the analysed types of bread and (2) the salt content in other cereal products available in the literature worldwide.
6. Statistica 13.3 software was used for statistical analysis. The mean value, standard deviation (SD), and standard error of the mean (SEM) were calculated. The calculations took into account two replicates for each sample. Statistically significant differences ($p \leq 0.0001$) were determined using the Tukey's HSD test.

## Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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## Author contributions

KJ-R designed the study, collected data, and wrote the first draft. AW developed the research idea, and reviewed and edited the manuscript. KJ-R and TC provided essential materials, and conducted the analyses. All authors reviewed and commented on the final manuscript draft.

## Declarations

### Competing interests

The authors declare no competing interests.

## Additional information

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**Supplementary Table S1.** The contribution of various cereal products to salt intake in children's diet.

| **Age group** | **Serving size (g)** | **Salt amount** | **% of recommended daily salt intake** | **References** |
| --- | --- | --- | --- | --- |
| **Bread*** | | | | |
| 1–3 | 20 | 360 mg | 19.2% | |
| 4–6 | 32.5 | 590 mg | 23.6% | own research |
| 7–9 | 45 | 820 mg | 27.2% | |
| 10–12 | 80 | 1450 mg | 44.6% | |
| **Pasta**** | | | | |
| 1–3 | 50 | 25 mg | 1.3% | |
| 4–6 | 60 | 30 mg | 1.2% | 1 |
| 7–9 | 100 | 50 mg | 1.7% | |
| 10–12 | 100 | 50 mg | 1.5% | |
| **Milk slices** | | | | |
| 1–3 | 31.7 | 91.8 mg | 4.9% | |
| 4–6 | 31.7 | 91.8 mg | 3.7% | 32 |
| 7–9 | 31.7 | 91.8 mg | 3.1% | |
| 10–12 | 31.7 | 91.8 mg | 2.8% | |

| | | | | |
|---|---|---|---|---|
| **Sweet breakfast cereals*** ** | | | | |
| 1–3 | 30 + 125 | 49.8 mg | 2.7% | |
| 4–6 | 30 + 125 | 49.8 mg | 2.0% | 31 |
| 7–9 | 30 + 125 | 49.8 mg | 1.7% | |
| 10–12 | 30 + 125 | 49.8 mg | 1.5% | |
| **Corn crisps******** | | | | |
| 1–3 | 30 | 390 mg | 20.8% | |
| 4–6 | 30 | 390 mg | 15.6% | 33 |
| 7–9 | 30 | 390 mg | 13.1% | |
| 10–12 | 30 | 390 mg | 12.1% | |
| **Crackers******** | | | | |
| 1–3 | 25 | 475 mg | 25.3% | |
| 4–6 | 25 | 475 mg | 19.1% | 34 |
| 7–9 | 25 | 475 mg | 15.8% | |
| 10–12 | 25 | 475 mg | 14.6% | |
| **Rice and corn waffles******** | | | | |
| 1–3 | 10 | 50 mg | 2.7% | |
| 4–6 | 10 | 50 mg | 2.1% | 34 |
| 7–9 | 10 | 50 mg | 1.6% | |

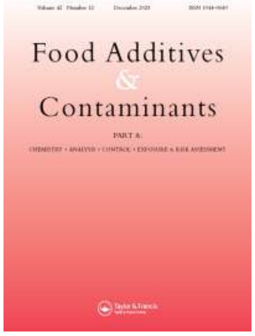
| | | | | |
|---|---|---|---|---|
| 10–12 | 10 | 50 mg | 1.5% | |
| | | **Flatbreads******** | | |
| 1–3 | 80 | 1336 mg | 71.3% | |
| 4–6 | 80 | 1336 mg | 53.4% | [34] |
| 7–9 | 80 | 1336 mg | 44.5% | |
| 10–12 | 80 | 1336 mg | 41.1% | |

*Serving size determined based on [29,30]

**Figures for pasta without added salt

***Flakes enriched with sugar, chocolate or honey during production, Serving size = amount of cereal recommended by the producer 30 g + 125 ml milk

****Serving size is based on food product labels and the recommendations from manufacturers included on the labels.

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# Sweet-tasting cereal products as a source of sodium and salt in children’s diets

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# Sweet-tasting cereal products as a source of sodium and salt in children's diets

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**ABSTRACT**
Sweet-tasting cereal products are frequently consumed as snacks and meal additives in children's diets. While the adverse impact of sugars added to these products has been explicitly confirmed, their significant contents of salt and sodium (Na) are often underestimated. The aims of this study were to investigate the Na content and calculate the salt amounts in sweetened cereal products, as well as to estimate their contribution to the sodium intake and coverage of the adequate intake (AI) of Na and salt in the diets of children aged <1, 1–3. 4–6, 7–10 and 11–14 years. The research material consisted of sweet cereal products ($n = 194$) purchased from grocery stores in Lublin, Poland. The average Na and salt contents (per 1,000 g) in the selected sweet cereal products can be ordered as follows: confectionery bakery products > breakfast cereals > cookies > cereal bars > cookies for babies and toddlers = rice waffles. Confectionery bakery products had the largest share across all age groups in Na and salt intakes, covering 8.9–14.3% of AI, followed by breakfast cereals: 2.7–4.6%, and cookies: 1.4–1.8%. Confectionery bakery products were the main sources of Na and salt to children aged 1–14 years among the analysed sweet cereal products. Current reports indicate that it is impossible to completely eliminate salt from sweet bakery products; however, reducing its quantity in recipes would contribute to lowering salt intake. Hence, there is a need for further analysis of sweet cereal products as sources of not only simple sugars but also salt.

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## Introduction

Sweet cereal products are very eagerly consumed by children (Piasecka and Lesiów, 2019; Potvin Kent et al., 2017; Sanchez-Siles et al., 2022). This preference is primarily linked to an evolutionary predisposition towards sweet tastes (similar to the flavour of breast milk) and family dietary habits (Sanchez-Siles et al., 2022; Farapti et al., 2024), as well as their high availability and wide variety. These products are predominantly sources of high amounts of simple sugars; hence, their consumption can lead to overweight and obesity, and subsequently to diet-related diseases (Magriplis et al., 2021). The products in question include sweet breakfast cereals and confectionery items (e.g. yeast buns, doughnuts, croissants, butter rolls). Confectionery products also contain significant amounts of saturated and trans-unsaturated fatty acids, adversely affecting the cardiovascular system and potentially increasing the risk of development of diet-related diseases in the future (Trattner et al., 2015).

Many individuals are, however, unaware that sweetened cereal products contain substantial amounts of salt and sodium (Na), which, when consumed in excess over time, can adversely affect the cardiovascular system and increase the risk of hypertension, heart disease, and stroke (World Health Organization., 2012; Rust and Ekmekcioglu, 2017). Epidemiological surveys conducted in 2015 revealed the prevalence of hypertension in over 4% of 6-year-olds, in more than 3% of 9-year-olds, and nearly 8% of 14-year-olds (Song et al., 2019). Excess salt intake can also detrimentally affect the proper development of children's osseous system and lead to excessive

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strain on their kidneys, which are less developed than those of adults (Dinmukhamedova et al., 2019). According to recommendations from the European Food Safety Authority (EFSA) and World Health Organisation (WHO), salt intake for individuals over the age of 11 should be limited to 5 g per day (World Health Organization., 2012; Turck et al., 2019), while daily salt intake should not exceed 0.5 g in infants aged 0–11 months, 2.75 g in children aged 1–3 years, and 3.25 g in children aged 4–6 years (Turck et al., 2019). The WHO recommended maximum intake of Na of 2,000 mg/day for adults should be proportionally reduced to account for the lower energy requirements of children, i.e.: 1,100 mg/day for children aged 1–3 years; 1,300 mg/day for children aged 4–6 years; 1,700 mg/day for children aged 7–10 years; and 2,000 mg/day for adolescents aged 11–17 years (World Health Organization., 2012). According to the Nutrition Standards for the population of Poland, the adequate intake (AI) for children is: 370 mg/day for infants aged 6–11 months; 750 mg/day for children aged 1–3 years; 1,000 mg/day for children aged 4–6 years; 1,200 mg/day for children aged 7–9 years; 1,300 mg/day for children aged 10–12 years; and 1,500 mg/day for children aged 13–15 years (Rychlik et al., 2024). Studies conducted so far have indicated children's diets across the globe to provide excess Na (Gowrishankar et al., 2020; Rodrigues et al., 2023; Johnson et al., 2019; Malczyk et al., 2024; Mohammadifard et al., 2021), with its main source being table salt (Malczyk et al., 2024; Mohammadifard et al., 2021). Therefore, it is crucial to make parents aware of the most significant sources of salt and Na in children's diets, especially those that are not immediately obvious. Although the U.S. Centres for Disease Control and Prevention (2025) identifies sweet snacks as a source of Na in the diet (among 11 listed food products), available studies treat salty and sweet products separately. A comprehensive understanding of this issue is necessary to implement effective strategies aimed at reducing the risk of lifestyle-related non-communicable diseases associated with excessive Na intake in the context of public health. Therefore, the present study aimed to assess the Na content and calculate salt amounts in sweetened cereal products as well as to estimate the extent to which these products contribute to the Na and salt intake in children.

## Materials and methods

### *Research material*

Sweet cereal products – $n = 214$ (breakfast cereals – $n = 38$, confectionery bakery products – $n = 78$, cookies – $n = 31$, cookies for babies and toddlers – $n = 10$, cereal bars – $n = 47$, rice waffles – $n = 10$), listed in Table 1, were purchased in 2024 and 2025 from grocery stores in Lublin (eastern

**Table 1.** Characteristics of the analysed sweet-tasting cereal products.

| Type of product | n | Sugar source | % of products with salt added |
|---|---|---|---|
| Breakfast cereal | 38 | | |
| Corn | 8 | Sugar, invert sugar syrup, molasses, honey, glucose syrup | 100 |
| Oatmeal | 5 | Sugar, glucose-fructose syrup | 60 |
| Muesli | 11 | Cane sugar, glucose syrup, glucose-fructose syrup, chocolate | 100 |
| Whole grains | 4 | Sugar, invert sugar syrup, glucose syrup, glucose-fructose syrup | 100 |
| Bran | 4 | Glucose-fructose syrup | 0 |
| Multi-cereal | 6 | Sugar, glucose syrup, chocolate, honey | 67 |
| Confectionery bakery products | 78 | | |
| Yeasty without additives | 15 | Sugar, glucose syrup | 100 |
| Yeast with additives | 25 | Sugar, glucose syrup | 100 |
| Made from puff pastry | 38 | Sugar, glucose syrup | 100 |
| Cookies | 31 | Sugar, cane sugar, glucose-fructose syrup, dextrose, invert sugar syrup, molasses, maltitol, isomalt, rice syrup | 87 |
| Cookies for babies and toddlers | 10 | Sugar, cane sugar, concentrated apple juice, apple puree, dried bananas | 0 |
| Cereal bars | 47 | | |
| Muesli | 25 | Sugar, cane sugar, honey, cane molasses, oligofructose, invert sugar syrup, maltose syrup, dextrose, dried dates, starch syrup, coconut sugar, glucose syrup, maltitol, maltodextrin, concentrated apple juice, glucose-fructose syrup | 68 |
| With filling | 12 | Sugar, glucose syrup, dextrose, rice syrup, sucrose | 17 |
| Sesame | 10 | Sugar, cane sugar, glucose syrup, honey, rice syrup | 0 |
| Rice waffles | 10 | Sugar, cane sugar, glucose-fructose syrup | 10 |

Poland). They were dried at a temperature of 65 °C for 24 h (WTB Binder dryer; Labortechnik GmbH, Tuttlingen, Germany), then ground separately in a laboratory mill equipped with plastic blades, and stored in tightly sealed glass containers until chemical analyses were performed (for a maximum of 2 weeks).

## Chemical analyses

### Mineralisation

The contents of each container were manually mixed to make the samples homogenous. Approximately 3 g of the sample were weighed in triplicate into pre-dried porcelain crucibles and dry-mineralized in a muffle furnace (FCF 22 SHM, Czylok, Jastrzębie Zdrój, Poland) at 550 °C, with 30% pure hydrogen peroxide $H_2O_2$ (POCH S.A., Lublin, Poland) used as the oxidising agent, following the procedures described in other studies (Winiarska-Mieczan et al., 2018; Jachimowicz et al., 2021). The resulting ash was dissolved in 10 mL of 1 M $HNO_3$ (POCH S.A., Lublin, Poland).

### Determination of the content of Na

The content of Na was determined using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer) with a 720-ES spectrometer (Varian, Palo Alto, CA, USA). Operating conditions for ICP-OES were as follows: RF generator power – 1.2 kW; plasma gas flow rate – 15.0 L/min; auxiliary gas flow rate – 2.25 L/min; nebuliser gas flow rate – 0.70 L/min; sample flow rate – 0.1 mL/min; replications – 4; read time – 15 s; peristaltic pump rotation speed – 12 rpm; determination parameters: wavelength – 589.592 nm, LOD (limit of detection) – 0.25 mg/kg, and LOQ (limit of quantification) – 0.39 mg/kg. The accuracy of the chemical analyses was verified using 1 M $HNO_3$ and two reference samples: LGC 7173 (poultry feed containing 1180 mg/kg Na; LGC Standards GmbH, Wesel, Germany) and NCS ZC73,009 (wheat containing 17.0 mg/kg Na; National Institute of Standards and Technology, Gaithersburg, MD, USA). The recovery rate of Na from LGC 7173 was 106%, while that from NCS ZC73,009 was 97%. The calibration curve was plotted with a standard Na solution (Ultra Scientific 1000 mg/L; 99.99% purity; LGC Standards Sp. z o.o., Kiełpin, Poland) used to prepare Na solutions with concentrations of 1, 2, 4, and 8 g/L. Each chemical analysis was repeated three times.

## Calculations

Based on the Na content of the analysed products, their salt content was calculated using the following formula (Turck et al., 2019; Commission Regulation (EU) 2017):

$$Sodium\ content\,(g) \times 2.54 = Equivalent\ salt\ content\,(g)$$

The serving size of the tested products are presented in Table 2. The Na content of one serving of the product was calculated according to the following formula:

$$Na\ content\ per\ serving\,(mg) = \left[\left(Na\ content\,\frac{g}{1{,}000\,g}\right) \times serving\,(g)\right] \times 1{,}000$$

The Na and salt contents in the analysed cereal products are presented per 1000 g and per

**Table 2.** Serving size of sweet-tasting cereal products, g.

| Type of product | Children's age, years <1 | 1–3 | 4–6 | 7–10 | 11–14 |
|---|---|---|---|---|---|
| Breakfast cereal | NR[g] | 30[g] | 30[g] | 30[g] | 30[g] |
| Confectionery bakery products | NR[d] | 50[a] | 50[e] | 50[e] | 65[e] |
| Cookies | NR[d] | NR[d] | 35[f] | 35[f] | 50[f] |
| Cookies for babies and toddlers | 9[b] | 9[b] | NR | NR | NR |
| Cereal bars | NR | 20[c] | 25[c] | 25[c] | 25[c] |
| Rice waffles | NR[d] | 15[h] | 15[h] | 15[h] | 15[h] |

[a]based on Weker et al. (2012); [b]manufacturer's suggested serving size, only for children <1 and 1–3 years old; [c]manufacturer's suggested serving size, as a snack for children's lunches; [d]based on Mother and Child Institute (2020) cited as *„Confectionery bakery products and cereal cakes are not recommended for children's nutrition due to the presence of fat containing unfavourable trans isomers, which, by increasing the concentration of "bad" cholesterol and lowering "good" cholesterol, increases the risk of atherosclerosis."*; [e]based on Weker et al. (2015); [f]manufacturer's suggested serving size, cookies for younger children weigh 35 g, for older children 50 g; [g]manufacturer's suggested serving size, based on Winiarska-Mieczan et al. (2016); for children <1 year of age, breakfast cereals (analysed in our study = sweetened) are contraindicated due to the presence of sugar; NR: not recommended.

serving. Calculations were performed in order to establish: (1) to what extent one serving of the product covers the Na requirement for children aged 1–14 years (AI – adequate intake) (Rychlik et al., 2024), and (2) how much salt is provided by one serving of the product to children aged 1–14 years compared to the recommended intake (Turck et al., 2019).

### *Statistical analysis*

Statistical analysis was conducted using Statistica 13.1 software (StatSoft, Krakow, Poland). Mean, minimum and maximum values, standard deviation (SD) were calculated, and analysis of variance was conducted. Three replicates were included in the calculations for each chemical analysis performed. Statistically significant differences ($p < 0.05$) were determined using one-way ANOVA with Duncan's test.

## Results

### *Na and salt contents in sweet cereal products*

Most of the analysed sweet cereal products contained added salt – all confectionery bakery products – 100%; most cookies – 87%; breakfast cereals (excluding bran) – 79%; and muesli cereal bars – 68%. In contrast, sesame bars – 100%; cookies for babies and toddlers – 100%; as well as most rice waffles – 90%; and cereal bars with filling – 83%, did not contain added salt (Table 1). The addition of salt to sweet cereal products contributed to an increase in their Na content.

In order, the Na and salt contents (per 1000 g) in the analysed products were ($p < 0.05$): confectionery bakery products (2.145 ± 0.693 g Na, 5.450 ± 1.761 g salt) > breakfast cereals (1.159 ± 1.107 g Na, 2.909 ± 2.844 g salt) > cookies (0.460 ± 0.016 g Na, 1.154 ± 0.040 g salt) > cereal bars (0.261 ± 0.188 g Na, 0.656 ± 0.472 g salt) > cookies for babies and toddlers (0.165 ± 0.019 g Na, 0.413 ± 0.048 g salt) = rice waffles (0.162 ± 0.026 g Na, 0.406 ± 0.074 g salt) (Figure 1, Table 3).

### *Sweet cereal products as a source of Na and salt in the diet of children aged 1–14 years*

The contribution of individual analysed sweet cereal products to the Na and salt intake with children's diets depended on: (1) the Na and salt contents in the products, (2) the recommended serving size of the product, and (3) the daily Na requirement. In children over 1 year of age, Na (and salt) was provided primarily ($p < 0.05$) from confectionery bakery products (8.93–14.3% AI), followed by breakfast cereals (2.67–4.64% AI), and cookies (1.36–1.79% AI), while the other products provided below 0.4% AI (Table 4). Products other than cookies for babies and toddlers are not recommended for children under 1 year of age. Given that salt = 2.54 × sodium, the correlations between products are identical for Na and salt (Figure 1).

The analysis of all products studied in the diet of children under 1 year of age showed that cookies for babies and toddlers were the only source of Na (Table 4). For children aged 1–3 years,

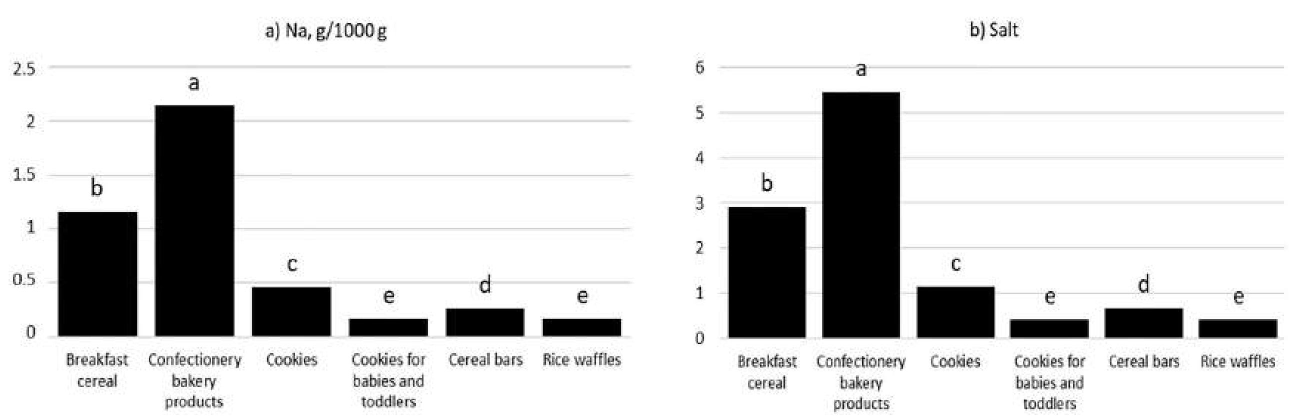


**Figure 1.** Mean Na and salt content of sweet-tasting cereal products tested-Duncan's test ($p < 0.05$).

**Table 3.** Mean Na and salt content of sweet-tasting cereal products tested.

| | g/kg | | 1 serving | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Na | | | | | Salt | | | | |
| | Na | Salt | <1 y | 1–3 y | 4–6 y | 7–10 y | 11–14 y | <1 y | 1–3 y | 4–6 y | 7–10 y | 11–14 y |
| Breakfast cereal | | | | | | | | | | | | |
| Mean | 1.159 | 2.909 | – | 0.035 | 0.035 | 0.035 | 0.035 | – | 0.087 | 0.087 | 0.087 | 0.087 |
| Minimum value | 0.108 | 0.273 | – | 0.006 | 0.006 | 0.006 | 0.006 | – | 0.015 | 0.015 | 0.015 | 0.015 |
| Maximum value | 4.043 | 10.27 | – | 0.082 | 0.082 | 0.082 | 0.082 | – | 0.205 | 0.205 | 0.205 | 0.205 |
| SD | 1.107 | 2.844 | – | 0.023 | 0.023 | 0.023 | 0.023 | – | 0.059 | 0.059 | 0.059 | 0.059 |
| Variance analysis | 1.226 | 8.086 | – | 5.48E−04 | 5.48E−04 | 5.48E−04 | 5.48E−04 | – | 0.003 | 0.003 | 0.003 | 0.003 |
| Confectionery bakery products | | | | | | | | | | | | |
| Mean | 2.145 | 5.450 | – | 0.107 | 0.107 | 0.107 | 0.139 | – | 0.269 | 0.269 | 0.269 | 0.350 |
| Minimum value | 1.002 | 2.546 | – | 0.049 | 0.049 | 0.049 | 0.064 | – | 0.123 | 0.123 | 0.123 | 0.160 |
| Maximum value | 2.786 | 7.076 | – | 0.151 | 0.151 | 0.151 | 0.196 | – | 0.378 | 0.378 | 0.378 | 0.492 |
| SD | 0.693 | 1.761 | – | 0.036 | 0.036 | 0.036 | 0.047 | – | 0.091 | 0.091 | 0.091 | 0.118 |
| Variance analysis | 0.481 | 3.100 | – | 0.001 | 0.001 | 0.001 | 0.002 | – | 0.008 | 0.008 | 0.008 | 0.014 |
| Cookies | | | | | | | | | | | | |
| Mean | 0.460 | 1.154 | – | – | 0.016 | 0.016 | 0.023 | – | – | 0.040 | 0.040 | 0.058 |
| Minimum value | 0.418 | 1.049 | – | – | 0.012 | 0.012 | 0.017 | – | – | 0.030 | 0.030 | 0.043 |
| Maximum value | 0.467 | 1.172 | – | – | 0.022 | 0.022 | 0.031 | – | – | 0.054 | 0.054 | 0.077 |
| SD | 0.016 | 0.040 | – | – | 0.003 | 0.003 | 0.004 | – | – | 0.008 | 0.008 | 0.011 |
| Variance analysis | 0.0003 | 0.0016 | – | – | 9.34E−06 | 9.34E−06 | 1.91E−05 | – | – | 5.88E−05 | 5.88E−05 | 1.17E−04 |
| Cookies for babies and toddlers | | | | | | | | | | | | |
| Mean | 0.165 | 0.413 | 1.48E−03 | 1.48E−03 | – | – | – | 3.72E−03 | 3.72E−03 | – | – | – |
| Minimum value | 0.128 | 0.321 | 1.15E−03 | 1.15E−03 | – | – | – | 2.89E−03 | 2.89E−03 | – | – | – |
| Maximum value | 0.188 | 0.473 | 1.68E−03 | 1.68E−03 | – | – | – | 4.25E−03 | 4.25E−03 | – | – | – |
| SD | 0.019 | 0.048 | 1.54E−04 | 1.54E−04 | – | – | – | 3.86E−04 | 3.86E−04 | – | – | – |
| Variance analysis | 0.002 | 0.011 | 2.37E−08 | 2.37E−08 | – | – | – | 1.49E−07 | 1.49E−07 | – | – | – |
| Cereal bars | | | | | | | | | | | | |
| Mean | 0.261 | 0.656 | – | 0.005 | 0.007 | 0.007 | 0.007 | – | 0.013 | 0.016 | 0.016 | 0.016 |
| Minimum value | 0.078 | 0.195 | – | 0.002 | 0.002 | 0.002 | 0.002 | – | 0.004 | 0.005 | 0.005 | 0.005 |
| Maximum value | 0.511 | 1.283 | – | 0.010 | 0.013 | 0.013 | 0.013 | – | 0.026 | 0.032 | 0.032 | 0.032 |
| SD | 0.188 | 0.472 | – | 0.004 | 0.005 | 0.005 | 0.005 | – | 0.009 | 0.012 | 0.012 | 0.012 |
| Variance analysis | 0.035 | 0.223 | – | 1.42E−05 | 2.21E−05 | 2.21E−05 | 2.21E−05 | – | 8.92E−05 | 1.39E−04 | 1.39E−04 | 1.39E−04 |
| Rice waffles | | | | | | | | | | | | |
| Mean | 0.162 | 0.406 | – | 2.43E−03 | 2.43E−03 | 2.43E−03 | 2.43E−03 | – | 6.09E−03 | 6.09E−03 | 6.09E−03 | 6.09E−03 |
| Minimum value | 0.132 | 0.332 | – | 1.98E−03 | 1.98E−03 | 1.98E−03 | 1.98E−03 | – | 4.97E−03 | 4.97E−03 | 4.97E−03 | 4.97E−03 |
| Maximum value | 0.206 | 0.517 | – | 3.09E−03 | 3.09E−03 | 3.09E−03 | 3.09E−03 | – | 7.76E−03 | 7.76E−03 | 7.76E−03 | 7.76E−03 |
| SD | 0.029 | 0.074 | – | 4.32E−04 | 4.32E−04 | 4.32E−04 | 4.32E−04 | – | 1.08E−03 | 1.08E−03 | 1.08E−03 | 1.08E−03 |
| Variance analysis | 0.001 | 0.014 | – | 1.87E−07 | 1.87E−07 | 1.87E−07 | 1.87E−07 | – | 1.18E−06 | 1.18E−06 | 1.18E−06 | 1.18E−06 |

The portions of the products are specified in Table 2; SD: standard deviation.

confectionery bakery products provided 73% of Na, breakfast cereals 24% of Na, rice waffles 2% of Na, while cookies for babies and toddlers and cereal bars each provided 1% of Na. In the case of children aged 4–6 and 7–10 years, confectionery bakery products provided 66% of Na, breakfast cereals 21% of Na, cookies 10% of Na, while cereal bars and rice waffles provided 1% of Na. In the diet of children aged 11–14 years, confectionery bakery products provided 69% of

**Table 4.** Share of one portion of sweet-tasting cereal products in the supply of Na in the diets of respective groups of children.

| | Children's age, years | | | | |
|---|---|---|---|---|---|
| | <1 | 1–3 | 4–6 | 7–10 | 11–14 |
| Reference Daily Intake (AI) | 370 mg | 750 mg | 1000 mg | 1200 mg | 1300 mg |
| Mean share of sweet-tasting cereal products in Reference Daily Intake (1), % | | | | | |
| Daily Na intake, mg | | | | | |
| Breakfast cereal | – | 4.64[b] | 3.47[b] | 2.89[b] | 2.67[b] |
| Confectionery bakery products | – | 14.3[a] | 10.7[a] | 8.93[a] | 10.7[a] |
| Cookies | – | – | 1.63[c] | 1.36[c] | 1.79[c] |
| Cookies for babies and toddlers | 0.40[a] | 0.20[d] | – | – | – |
| Cereal bars | – | 0.21[d] | 0.20[d] | 0.17[e] | 0.15[e] |
| Rice waffles | – | 0.31[c] | 0.23[d] | 0.19[d] | 0.18[d] |
| Share in the supply of Na, %[2] | | | | | |
| Breakfast cereal | 0 | 24 | 21 | 21 | 17 |
| Confectionery bakery products | 0 | 73 | 66 | 66 | 69 |
| Cookies | 0 | 0 | 10 | 10 | 12 |
| Cookies for babies and toddlers | 100 | 1 | 0 | 0 | 0 |
| Cereal bars | 0 | 1 | 1 | 1 | 1 |
| Rice waffles | 0 | 2 | 1 | 1 | 1 |

[1]based on Rychlik et al. (2024); [2]daily supply with sweet-tasting cereal products was adopted as 100%; AI:adequate intake; [a, b, c]means with different superscripts in the same rows differs significantly at $p < 0.05$ by Duncan's test.

Na, breakfast cereals 17% of Na, cookies 12% of Na, and cereal bars and rice waffles each provided 1% of Na (Table 4).

## Discussion

### *Determinants of children's taste preferences and the role of salt in sweet cereal products*

Nutritional preferences mean predispositions to choose specific types of foods upon the influence of various factors, such as social factors (e.g. level of education, occupation, family status), cultural factors (eating habits in the family and society related to culture and/or religion), and psychological factors (Malczyk et al., 2024; Lisičić-Konaković et al., 2023). Preferences can develop from improper eating habits ingrained in childhood (Kozłowska et al., 2017). The preference for sweetened products stems from evolutionary factors (the sweet taste of breast milk) (Farapti et al., 2024). In turn, the U.S. Centres for Disease Control and Prevention (2025) emphasises that about 90% of children consume more salt than they need. Salt is added to sweet products to balance flavours and enhance the sweet taste, preventing it from becoming overly bland (Vucurovic et al., 2017). However, this can also lead to a higher sugar content in the product. Adding salt during the dough preparation phase suppresses amylase activity, reduces starch susceptibility to amylolysis, and increases starch gelatinisation temperature, which in turn affects the dough structure after baking (Vucurovic et al., 2017).

### *Contribution of sweet cereal products to sodium intake in children*

Sweet cereal products were found to contain considerable amounts of Na and salt (0.162–2.145 g Na per 1,000 g; equivalent to 0.406–5.45 g of salt). Depending on portion size and age group, a single serving – particularly of confectionery bakery products – may provide up to 0.5 g of salt. Previous analyses reported comparable findings: milk slice type bars supplied on average 91.8 mg Na per serving (0.74 g salt per 100 g) (Jachimowicz-Rogowska et al., 2023), and milk biscuits 0.215–0.37 g Na per 100 g (Muneer et al., 2020). Even traditionally sweet bakery products such as Czech Christmas bread (2 g of salt per 100 g (Boudová Pečivová et al., 2013) or gluten-free biscuits 0.17–0.32 g of salt per 100 g (Luque-Vilca et al., 2024) contained noteworthy amounts of salt. Considering that EFSA recommends maximum daily salt intakes of 3.25 g for children aged 4–6 years and 4.25 g for children 7–10 years olds (Turck et al., 2019), these products can substantially contribute to exceeding dietary sodium targets. Given their popularity and frequent consumption among children, sweet cereal-based snacks represent a relevant and often underestimated source of sodium, underscoring the need for continuous reformulation and salt-reduction strategies (Jachimowicz-Rogowska et al., 2025).

### Effect of salt reduction on the quality and sensory properties of sweet cereal products

Is it possible to reduce salt content without compromising the quality of sweet cereal products? A previous study has shown that too drastic a reduction in the amount of salt added to the dough used to produce sweet biscuits significantly increased the rate of water loss during baking, adversely affecting the hardness of the cookies, reducing their breaking strength (Ayed et al., 2018). The authors explained this outcome by the positive effect of table salt on gluten cross-linking. In a study by Ayed et al. (Ayed et al., 2021), sensory analyses demonstrated that reducing the salt content by 33% (from 1.05 g to 0.86 g of salt per 100 g) positively influenced the taste, aroma, and texture of sweet shortbread cookies. In this study, lower levels of added salt resulted in more crispy products having larger gas cells in the dough formed during the baking process. However, the absence of salt in the dough led to lower resistance to breakage and poorer taste and aroma ratings (salt plays a key role in retaining hydrophobic volatile substances). Similarly, Pareyt et al. (2009) found that by influencing the water content in the dough, salt has both a molecular and microstructural effect on the crispness of biscuits, but a reduction of its content is more frequently recommended. Reducing salt content in the dough decreases the dough's resistance to stretching, leading to the formation of larger gas bubbles (Avramenko et al., 2020).

### Contribution of sweet cereal products to energy and sodium intake in children's diets

When interpreting the sodium content of the sweet cereal products analysed, their relative contribution to both energy intake and total sodium intake in children's diets should be considered. Although sweet cereal products typically contribute less than 10% (3–5%) of children's energy intake, their share of total sodium intake varies depending on study methodology, product classification and definition, and country – in the Williams study (Williams, 2014), ready-made breakfast cereals contributed only about 1–2.6% of sodium intake, whereas products such as biscuits, cakes, scones, and doughnuts accounted for 5% (Marrero et al., 2014). This shows that differences in product classification and study methodology explain the discrepancies. The main sources of sodium in children's diets, however, remain bread and bakery products, processed meats, and cheeses (Marrero et al., 2014). Nevertheless, sweet cereal-based snacks are frequently consumed between meals and outside parental supervision, representing an additional and potentially underestimated source of sodium (Jachimowicz-Rogowska et al., 2025).

The observed sodium levels in our study are therefore relevant in the context of public health goals aimed at reducing sodium intake. Although their contribution to total dietary sodium is lower than that of savoury products, reformulation efforts in this category could have a tangible impact on children's overall sodium exposure, particularly given the frequency of consumption and the marketing of these products targeted at young consumers. Future research combining information on the composition with dietary intake assessments is warranted to better determine the proportional contribution of sweet cereal products to total sodium intake and evaluate the balance between sodium content and energy density in this food category.

### Impact of leavening agents on acrylamide formation and sodium content in cereal products

Ammonium hydrogen carbonate ($NH_4HCO_3$, ammonium bicarbonate) has long been used as a leavening agent in dry bakery products (e.g. cookies, crackers, some cereal bars). Literature reports that $NH_4HCO_3$ promotes acrylamide formation in sweet bakery products. Mechanisms include sugar fragmentation (formation of α-diketones, glyoxal, methylglyoxal), reactions with asparagine, and the influence of pH on Maillard reaction pathways, which increase acrylamide levels (Mireault et al., 2023; Amrein et al., 2006). Consequently, the industry often recommends replacing $NH_4HCO_3$ with a combination of sodium-based leavening agents (e.g. $NaHCO_3$, sodium bicarbonate) or other alternatives to reduce acrylamide concentration (Zhang and Zhang, 2007). Substituting leavening agents in cereal products is currently a relevant research problem. In the study by Zhang et al. (Marianelli et al., 2025), the use of $NaHCO_3$ in acrylamide-reduction strategies for crackers was analysed. Similarly, Mesias et al. (Zhang et al., 2022) investigated partial or complete replacement of $NH_4HCO_3$ with $NaHCO_3$. However, this approach has a trade-off: replacing ammonium-based leavening with a sodium-based alternative reduces acrylamide content but may increase the product's sodium content, particularly if larger amounts of the sodium salt are used as a substitute (Mesías et al., 2019; Sarion et al., 2021; Lo Faro et al., 2022). Therefore, when assessing sources of sodium in bakery products, possible recipe modifications implemented by manufacturers in response to acrylamide-reduction requirements should be considered. Authors discussing this trade-off recommend evaluating total sodium content after any recipe change or the use of alternatives, such as calcium/divalent compounds or the enzyme asparaginase (United States Department of Agriculture., 2025; Rannou et al., 2016). Technological changes aimed at reducing acrylamide represent a credible source of elevated sodium levels and constitute an important interpretative context. The drawback of higher sodium levels in products should be considered in the context of public health strategies aimed at reducing sodium intake (Food and Drug Administration, 2021).

To assess whether the replacement of leavening agents ($NH_4HCO_3$ with $NaHCO_3$), implemented to limit acrylamide formation, is associated with increased sodium content in cereal and confectionery bakery products, we compared literature findings. European Commission Regulation (EU) 2017/2158 (Commission Regulation (EU) 2017) requires producers in Europe to implement measures to reduce acrylamide, which increases the likelihood of recipe reformulation. Experimental and review studies confirm that replacing $NH_4HCO_3$ with sodium-based alternatives significantly lowers acrylamide concentrations but may simultaneously raise the sodium load of the formulation (Zhang et al., 2022; Mesías et al., 2019). The literature shows considerable heterogeneity in sodium content trends in cereal products: while the sales-weighted average sodium content in breakfast cereals decreased in the United Kingdom between 2015 and 2020 (Williams, 2014), monitoring in other countries revealed increases in bakery subcategories. For example, in Slovenia, the average sodium content in the "cakes, muffins, and pastry" category increased between 2011 and 2015 (Commission Regulation (EU) 2017), and an Italian market analysis indicated a substantial exceedance of recommended limits in the "crackers/savory biscuits" category and bakery products (Pravst et al., 2017). The observed increase in sodium in some sweet cereal products may reflect local reformulation trends; however, without product-specific longitudinal data (ingredient lists from different years, information on reformulations), this rise cannot be definitively attributed solely to the replacement of $NH_4HCO_3$ with Na compounds.

## Conclusions

Based on the analysis of the recipe composition provided on the labels of selected sweet cereal products, salt addition was confirmed in all confectionery bakery products and most cookies, breakfast cereals (excluding bran ones), and muesli cereal bars, while no added salt was found in sesame bars or cookies for babies and toddlers. The average Na and salt contents (per 1000 g) in selected sweet cereal products can be summarised as follows: confectionery bakery products > breakfast cereals > cookies > cereal bars > cookies for babies and toddlers = rice waffles. Confectionery bakery products had the largest share across all age groups of children in their Na and salt intakes, providing 8.9–14.3% of AI coverage, followed by breakfast cereals: 2.7–4.6%, and cookies: 1.4–1.8%.

In conclusion, among the sweet cereal products analysed, confectionery bakery products were the primary sources of Na and salt for children aged 1–14 years. Although these products are considered and called "sweet", most of them contain added salt and can provide significant amounts of Na in the diet of children. Products such as cookies for babies and toddlers, cereal bars, and rice waffles may be more recommendable to children as they contain lower Na levels compared to the other analysed products, and moreover, most of them have no added salt in their recipes.

## Perspectives

Salt is present in many food products that consumers do not perceive as salty. This "hidden salt" can offer functional benefits in production processes but is often overlooked in strategies aimed at reducing Na intake and preventing diseases developed due to its excess consumption. At the current stage of knowledge, it is impossible to completely eliminate salt from sweet bakery products; however, reducing its quantity in recipes would contribute to lowering salt intake, which is important from the standpoint of public health given the concern for the risks of cardiovascular diseases. Especially for obese and/or hypertensive children, diet management should focus on reducing the amount of Na while increasing the consumption of potassium, which, in practice, in most cases means an increase in the consumption of vegetables and fruits (SINU Young Working., 2022). The paucity of available studies addressing Na and salt contents in sweet cereal products, which are important food products in children's diets, underscores the need to analyse these products as sources of not only sugar but also salt. This is a critical aspect for developing strategies to reduce salt intake by children in order to minimise the risk of development of lifestyle-related diseases.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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ORIGINAL PAPER

# Milk slices as a source of macroelements and microelements in the diet of pre-schoolers

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**Abstract**

Sponge cake bars with milk filling, commonly referred to as milk slices, are a very frequent choice among children. These products are considered convenience foods consumed for breakfast and snacks during the day. They owe their popularity to commercials promoting these sweets as products that, in terms of calcium content, can successfully replace a glass of milk. Unfortunately, due to such associations, young consumers habitually choose highly sweetened products of low nutritional value. Since milk slices are very popular components of children's diets, they should be a source of essential nutrients, including mineral elements. This paper aimed to assay the level of selected macroelements (Ca, Mg, K, and Na) and microelements (Fe, Cu, and Zn) in sponge cake bars of milk slice type ($n$=15). The mean content of macroelements in the analysed products can be represented as K (3724 mg kg$^{-1}$ ± 502.0) > Na (2703 mg kg$^{-1}$ ± 2366) > Ca (1393 mg kg$^{-1}$ ± 646.7) > Mg (489.4 mg kg$^{-1}$ ± 211.9). The mean content of microelements in the analysed products can be represented as Fe (24.53 mg kg$^{-1}$ ± 13.19) > Zn (8.946 mg kg$^{-1}$ ± 2.444) > Cu (2.188 mg kg$^{-1}$ ± 0832.7). When considering the daily requirement of pre-schoolers (aged 4-6) for the analysed minerals, it was established that, on average, one serving of a milk slice (31.7 g) supplies 17.9% RDA Cu, 12.5% RDA Mg, 10.7% AI K, 9.2% AI Na, 8.0% RDA Fe, 5.8% RDA Zn, and 4.1% RDA Ca. Our findings imply that milk slices are not a good source of minerals in pre-schoolers' diets.

**Keywords:** cereal bars, children's nutrition, milk slices, minerals, sponge cake

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# INTRODUCTION

Sweet snacks are a daily component of the diets of both adults and children (Kmiecik et al. 2016). Nutrition experts recommend reducing the consumption of sugar and confectionery products. However, it is observed that sweets are invariably a popular choice of consumers (Maćków et al. 2020). Since these products are very popular components, they should be a source of essential nutrients, including minerals. Consumers perceive milk slices as highly nutritional products because commercials portray them as a source of calcium and an energy snack after breakfast.

Pre-schoolers' excessive or insufficient energy and nutrient intake can prevent their full psychophysical development and optimum health. A child spends about six or seven hours a day at nursery school, so the quality of food in the meals served to them is important.

It should be remembered that growing children are particularly sensitive to all food deficiencies (Orkusz, Włodarczyk 2014). Over the first three years of the child's life, their brain achieves

a weight that is only 200 grams smaller than the completely developed adult brain. Therefore, special attention should be paid to supplying the child with all nutrients, including macro- and microelements, necessary for the correct development of the structure and functions of the brain and all the other body organs and systems (Anjos et al. 2013). Surveys covering the population of pre-schoolers in Poland showed that their diets are poor, among other elements, in calcium (Kwiecień et al. 2015) and vitamin D (Dymkowska-Malesa, Szparaga 2013). The deficiency of vitamins D and K2 and calcium is the main reason for insufficient mineralisation of the skeletal system and low peak bone mass (Zaręba et al. 2012). This group of consumers is also characterised by insufficient intake of iron, which increases the child's susceptibility to respiratory infections and disorders of cognitive functions (Libera et al. 2018), and potassium showing antagonistic activity to sodium (Eckel et al. 2014). As regards sodium, its excess in the diet is a more common problem than its deficiency (Kwiecień et al. 2015), mostly due to the consumption of food with a considerable addition of table salt (Surma et al. 2020). Excessive salt intake increases the risk of hypertension (Eckel et al. 2014) and obesity (Kwiecień et al. 2017).

This paper aimed to estimate whether milk slices are a good source of selected macroelements: calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and microelements: iron (Fe), copper (Cu), and zinc (Zn) in the diet of pre-schoolers.

# MATERIAL AND METHODS

## Study material

Milk slices ($n$=15; Figure 1) and 2% cow's milk ($n$=10) were purchased at groceries in Lublin, between January and May 2021. All the products were ahead of their use-by dates. After the bars were ground in a laboratory grinder (Bosch, München, Germany), 3 g of the sample were weighed

Fig. 1. Analysed milk sandwich bars

in three replications. The milk was mixed manually, and ca. 3 g of the sample was weighed. All the samples were dried in a WTB Binder dryer (Labortechnik GmbH, Tuttlingen, Germany) at 105°C for 12 h, and then mineralised in a muffle furnace (FCF 22 SHM, Czylok, Jastrzębie Zdrój, Poland) using hydrogen peroxide as an oxidant (temperature 550°C, 12 h). White ash from mineralisation was dissolved in 10 ml of 1M $HNO_3$. The content of Na, K, Ca, Mg, Zn, Cu, and Fe was assayed using ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometers) in a 720-ES spectrometer (Varian, Palo Alto, CA, USA). The mineral assay parameters are presented in Table 1. Detailed methods are described elsewhere (Winiarska-Mieczan et al. 2018, Jachimowicz et al. 2021).

## Calculations and statistical analysis

The levels of Na, K, Ca, Mg, Zn, Cu and Fe in milk slices were given per product serving, one serving equivalent to one bar (16-50 g; on average 31.7 g). In addition, we calculated the extent to which one product serving covered the requirement of pre-schoolers (aged 4-6) for minerals according to the current Nutrition Standards for the Population of Poland, that is, AI (adequate intake) for Na and K, and RDA (recommended daily allowance) for Ca, Mg, Fe, Zn, Cu (Jarosz et al. 2020). The results were processed

Table 1

Parameters for the determination of minerals

| Minerals | Wavelength (nm) | LOD (mg kg$^{-1}$) | LOQ (mg kg$^{-1}$) |
|---|---|---|---|
| Na | 589.6 | 0.250 | 0.390 |
| K | 769.9 | 1.040 | 1.270 |
| Ca | 422.7 | 0.030 | 0.050 |
| Mg | 280.3 | 0.030 | 0.080 |
| Zn | 202.5 | 0.060 | 0.090 |
| Cu | 213.6 | 0.030 | 0.060 |
| Fe | 238.2 | 0.030 | 0.050 |

LOD – limit of detection, LOQ – limit of quantification

in Microsoft Excel 2010. Statistical analysis of results was carried out by one-way analysis of variance (ANOVA) using Statistica 13.1 software (StatSoft, Krakow, Poland). The Duncan's test established statistically significant differences ($P$<0.05). Correlations between minerals were calculated using the Pearson's correlation coefficient.

## RESULTS AND DISCUSSION

The content of macro- and microelements in respective milk slices is presented in Table 2. The content of the analysed minerals differed depending on the composition of milk slices. One serving contained from 11.23-63.48 mg Ca, 6.53-52.3 mg Mg, 62.1-169.6 mg K, 6.28-377.2 mg Na, 0.102-1.951 mg Fe, 0.015-0.137 mg Cu and 0.137-0.620 mg Zn. Bar no. 2 featured the highest ($P$<0.05) content of all elements, except Ca, Mg and Zn, and bar no. 10 – the lowest ($P$<0.05) content of all elements, except Ca, Na and Cu. The mean level of micro- and macroelements in the analysed products per average serving (31.7 g), referring to requirement coverage, can be presented as Cu (0.07 mg ± 0.04) > Mg (16.3 mg ± 11.0) > K (117.6 mg ± 30.9) > Na (91.8 mg ± ± 100.9) > Fe (0.8 mg ± 0.5) > Zn (0.29 mg ± 0.1) > Ca (40.9 mg ± 17.3). The biggest difference between the minimum and maximum values was observed for Na, and the smallest for K.

Statistically significant ($P$<0.05) positive correlations between minerals contained in milk slices were observed only for Mg and Zn ($r$=0.795) and for Cu and Zn ($r$=0.637) (Table 3).

### Calcium

One milk slice serving, on average, supplied nearly 41 mg Ca (1393 mg kg$^{-1}$ ± ± 646.7), which covered 4.1% of the requirement (1000 mg) of children aged 4-6 for that element (Table 4). The findings of Pagamunici et al. (2014) were

Table 2

The content of minerals in 1 serving of milk sandwich bar ($n$=15)

| $n$ | Package weight | Ca (mg) | Mg (mg) | K (mg) | Na (mg) | Fe (mg) | Cu (mg) | Zn (mg) |
|---|---|---|---|---|---|---|---|---|
| 1 | 28 | $50.82^{e}$ | $12.34^{d}$ | $122.7^{e}$ | $35.53^{d}$ | $1.071^{h}$ | $0.051^{cd}$ | $0.218^{b}$ |
| 2 | 50 | $18.24^{b}$ | $21.54^{h}$ | $169.6^{g}$ | $257.5^{k}$ | $1.951^{j}$ | $0.137^{h}$ | $0.447^{i}$ |
| 3 | 30 | $50.02^{e}$ | $14.10^{e}$ | $107.4^{c}$ | $21.09^{b}$ | $0.989^{h}$ | $0.074^{e}$ | $0.313^{f}$ |
| 4 | 29 | $61.08^{f}$ | $11.94^{c}$ | $102.0^{c}$ | $75.93^{h}$ | $0.552^{e}$ | $0.045^{c}$ | $0.199^{c}$ |
| 5 | 30 | $57.18^{f}$ | $19.72^{h}$ | $121.7^{e}$ | $25.27^{bc}$ | $0.459^{d}$ | $0.116^{g}$ | $0.417^{h}$ |
| 6 | 32 | $11.23^{a}$ | $12.67^{d}$ | $86.70^{b}$ | $66.12^{g}$ | $0.564^{e}$ | $0.075^{e}$ | $0.220^{cd}$ |
| 7 | 29 | $63.48^{f}$ | $9.950^{b}$ | $125.3^{e}$ | $155.5^{j}$ | $0.877^{gh}$ | $0.044^{c}$ | $0.195^{b}$ |
| 8 | 32 | $51.00^{e}$ | $17.90^{g}$ | $128.9^{e}$ | $60.06^{fg}$ | $0.694^{f}$ | $0.068^{e}$ | $0.276^{e}$ |
| 9 | 29 | $52.20^{ef}$ | $6.530^{a}$ | $80.60^{b}$ | $95.61^{i}$ | $0.196^{b}$ | $0.015^{a}$ | $0.145^{a}$ |
| 10 | 16 | $24.67^{c}$ | $6.810^{a}$ | $62.11^{a}$ | $28.93^{c}$ | $0.102^{a}$ | $0.033^{b}$ | $0.137^{a}$ |
| 11 | 28 | $47.19^{e}$ | $9.460^{b}$ | $99.61^{c}$ | $57.62^{f}$ | $1.074^{h}$ | $0.038^{b}$ | $0.255^{d}$ |
| 12 | 28 | $48.23^{e}$ | $12.89^{d}$ | $113.9^{d}$ | $46.91^{e}$ | $0.343^{c}$ | $0.055^{d}$ | $0.293^{f}$ |
| 13 | 40 | $15.24^{ab}$ | $20.77^{h}$ | $168.1^{g}$ | $377.2^{l}$ | $0.837^{g}$ | $0.137^{h}$ | $0.358^{g}$ |
| 14 | 45 | $30.07^{d}$ | $52.35^{i}$ | $160.0^{f}$ | $6.281^{a}$ | $0.804^{g}$ | $0.106^{g}$ | $0.620^{j}$ |
| 15 | 30 | $33.27^{d}$ | $15.03^{f}$ | $115.0^{d}$ | $67.39^{g}$ | $1.540^{i}$ | $0.081^{f}$ | $0.245^{d}$ |
| Average (for 31.7 g) | | 40.93 | 16.27 | 117.6 | 91.80 | 0.804 | 0.072 | 0.289 |
| Maximum | | 63.48 | 52.35 | 169.6 | 377.2 | 1.951 | 0.137 | 0.620 |
| Minimum | | 11.23 | 6.530 | 62.10 | 6.280 | 0.102 | 0.015 | 0.137 |
| SD | | 17.27 | 11.02 | 30.91 | 100.9 | 0.491 | 0.038 | 0.128 |
| Variance analysis | | 298.4 | 121.4 | 955.6 | 10183 | 0.241 | 0.001 | 0.016 |

SD – standard deviation; $^{a, b, c, \dots}$ – values with different superscripts differ at $P$<0.05 by the Duncan's test.

Table 3

Pearson correlations coefficients for minerals in milk sandwich bars

| Minerals | Ca | Mg | K | Na | Fe | Cu | Zn |
|---|---|---|---|---|---|---|---|
| Ca | 1.000 | -0.318 | 0.346 | -0.325 | -0.053 | -0.467 | -0.128 |
| Mg | -0.318 | 1.000 | 0.179 | -0.309 | -0.245 | 0.457 | **0.795** |
| K | 0.346 | 0.1798 | 1.000 | 0.183 | -0.022 | 0.254 | 0.294 |
| Na | -0.325 | -0.309 | 0.183 | 1.000 | 0.093 | 0.136 | -0.364 |
| Fe | -0.053 | -0.246 | -0.022 | 0.093 | 1.000 | -0.099 | -0.263 |
| Cu | -0.467 | 0.457 | 0.254 | 0.136 | -0.099 | 1.000 | **0.637** |
| Zn | -0.128 | **0.795** | 0.294 | -0.364 | -0.263 | **0.637** | 1.000 |

Values significant at $P \leq 0.05$ are highlighted in bold

Table 4

Demand of children aged 4-6 for selected macro- and microelements and their intake with 1 average portion of the product (31.7 g)

| Minerals | Demand (mg) (Jarosz et al. 2020) | Intake with 1 serving (mg) | Coverage of demand (%) |
|---|---|---|---|
| Ca | 1000 | 40.9 | 4.1 |
| Mg | 130 | 16.3 | 12.5 |
| K | 1100 | 117.6 | 10.7 |
| Na | 1000 | 91.8 | 9.2 |
| Fe | 10 | 0.8 | 8 |
| Cu | 0.4 | 0.07 | 17.9 |
| Zn | 5 | 0.29 | 5.8 |

to the contrary. The main element of gluten-free amaranth bars they analysed was Ca. In the study of Agbaje et al. (2014), the content of Ca in rice flake cereal bars ranged from 186.54 to 482.89 mg $kg^{-1}$, which is lower than the value we measured. On average, the Ca content in apricot-date bars was 1018 mg $kg^{-1}$ of the product (Rehman et al. 2012). Compared with the results of Ananthan et al. (2012), the high-protein cereal bar contained only 8.9 mg Ca $kg^{-1}$. Thus, it can be claimed that milk slices contain more Ca than bars of other types, but still, these amounts are insufficient to be regarded as a good source of Ca in the diet. Dymkowska-Malesa and Szparaga (2013), evaluating the diets of the pre-school population, found that Ca was the most frequently deficient mineral. Children's diets are poor in Ca (up to 70% deficiencies) in relation to the growing body's needs (Zyśk et al. 2020). An insufficient supply of Ca in a diet is an adverse practice. This is particularly dangerous for young children since deficient levels of Ca are refilled at the expense of bone tissue, which increases the rate of decreasing bone density. Calcium is the most essential mineral for building bones and teeth (Zyśk et al. 2020). Excessive fat intake from milk slices and protein reduces Ca absorption from the gastrointestinal tract and contributes to increased excretion of Ca with urine (Orkusz, Olech 2014).

### Magnesium

One milk slice serving, on average, supplied nearly 16.3 mg Mg (489.4 mg $kg^{-1}$ ± 211.9), which covered 12.5% of the requirement (130 mg) of children aged 4-6 for that element (Table 4). According to Bancerz et al. (2012), a 50 g milk bar contains 28 mg Mg, which is nearly equivalent to one serving of 2% fat milk. In the study of Agbaje et al. (2014), the content of Mg in cereal bars ranged from 88 to 160.14 mg $kg^{-1}$, which is more than three times lower than the value we measured. By contrast, Pagamunici et al. (2014) demonstrated that cereal bars contained much more Mg – on average, 2799 mg kg$^{-1}$ – compared with our findings. Goluch-Koniuszy's (2010) study shows that Polish children consume less Mg than required (covering 73-83% of the requirement). Kwiecień et al. (2015) evaluated the supply of Mg in a pre-schooler's food ration as correct (covering 86% of the requirement), but Dymkowska-Malesa and Szparaga (2013) and Zyśk et al. (2020) observed that the supply of Mg in the diet of pre-schoolers was above standard (183-226% of the requirement). A statistically significant positive correlation was identified between the level of cognitive development of children aged 4-6 and the intake of Mg (Zyśk et al. 2020). Some researchers found that children with attention deficit hyperactivity disorder (ADHD) had considerably lower levels of Mg in the blood serum than healthy children (Effatpanah et al. 2019), but a random blind study did not confirm that Mg supplementation could be effective in the treatment of such disorders (Ghanizadeh 2013).

## Potassium

One milk slice serving, on average, supplied about 118 mg K (3724 mg kg$^{-1}$ ± ± 502), which covered nearly 11% of the requirement (1100 mg) of children aged 4-6 for that element (Table 4). In the study of Rehman et al. (2012), the content of K in dried fruit bars was 6400 mg kg$^{-1}$ product. The difference between the content of K in milk slices and apricot-date bars can be due to the fact that dried fruit is a good source of K in the diet (Kunachowicz et al. 2020). The study by Kwiecień et al. (2015) attested to the insufficient intake of K by pre-schoolers (covering 27% of the requirement). A diet poor in K and rich in Na is a risk factor for developing hypertension (Lava et al. 2015).

## Sodium

One milk slice serving, on average, supplied ca. 92 mg Ca (2703 mg kg$^{-1}$ ± ± 2366), which covered 9.2% of the requirement (1000 mg) of children aged 4-6 for that element (Table 4). The content of Na in rice flakes cereal bars ranged from 70.54 to 235.86 mg kg$^{-1}$ (Agbaje et al. 2014), which was much lower than what we measured. Also, the apricot-date bars examined by Rehman et al. (2012) contained less Na (on average 231 mg kg$^{-1}$) than we determined. Despite being essential for humans, Na is harmful in larger amounts as it increases the risk of hypertension, occurring in 3.5%-4% of the children's population (Flynn et al. 2017). The diet of children contains excessive amounts of sodium (184.2% of the requirement) (Kwiecień et al. 2015) due to the fact that almost every foodstuff contains table salt and, additionally, salt is added to meals on the table (Surma et al. 2020). The Polish Society of Hypertension currently recommends that daily salt intake should not exceed 5 g (2 g Na) – Tykarski et al. (2019). It should be noted that every time the level of Na is increased by 100 mmol, 1 mmol Ca is excreted with urine (Blackwood et al. 2001), and every 1 g Na supplied to the body results in the excretion of 26 mg Ca with urine (Goluch-Koniuszy 2010), which is particularly alarming given the common Ca deficiency in children's diets (Kwiecień et al. 2015).

### Iron

One milk slice serving, on average, supplied nearly 1 mg (0.8 mg) Fe (24.53 mg $kg^{-1}$ ± 13.19), which covered 8% of the requirement (10 mg) of children aged 4-6 for that element (Table 4). The content of Fe in cereal bars in the study of Agbaje et al. (2014) ranged from 33.64 to 41.52 mg $kg^{-1}$, which is higher than we measured. Rehman et al. (2012) assayed even higher levels of Fe (on average 49.6 mg $kg^{-1}$) for dried fruit bars, while Padmashree et al. (2012) and Padmashree et al. (2013) observed levels lower than both milk slices, rice flakes cereal bars and dried fruit bars – on average, respectively, 9.46 mg Fe $kg^{-1}$ (in high-protein cereal bars) and 6.31 mg Fe $kg^{-1}$ (in flaxoat nutty bars). Zyśk et al. (2020) noted the insufficient coverage of the requirement for Fe in children aged 3 (6.94 mg ± 1.31) and 4-6 (7.09 mg ± 1.48). Insufficient intake of this element leads to anaemia, which can be particularly hazardous for pre-schoolers (Dymkowska-Malesa, Szparaga 2013). Fe deficiency can affect the school results of children at any age. Fe deficiency in a child's body results in reduced activity of brain enzymes, attention deficit, quick fatigue, inhibited mental development and learning disorders (Anjos et al. 2013).

### Copper

One milk slice serving, on average, supplied slightly 0.1 mg (0.07 mg) Cu (2,188 mg $kg^{-1}$ ± 0.832), which covered 18% of the requirement (0.4 mg) of children aged 4-6 for that element (Table 4). In the study of Agbaje et al. (2014), the content of Cu in rice flake cereal bars ranged from 11.86 to 13.73 mg $kg^{-1}$, which is five times higher than the value measured in our study, and which covers the Cu requirement of pre-schoolers. In the study of Zurita-Ortega et al. (2020), the content of Cu in two out of thirty-five dietetic cereal bars exceeded safe levels and was considered potentially toxic. The supply of Cu exceeded standard levels (more than double) in the diet of 3-year-olds (0.88 mg ± 0.20) and 4-6-olds (0.92 mg ± 0.21) in the study conducted by Zyśk et al. (2020), who also identified a statistically significant positive correlation between the level of cognitive development of children aged 4-6 and the intake of Cu with the diet. Cu deficiency can adversely affect brain function, and adequate intake of Cu positively affects children's cognitive functions (Anjos et al. 2013). However, excessive intake of this microelement can have a deleterious effect on cognitive processes. Zhou et al. (2015) observed that excessive concentration of Cu in the blood serum adversely affects the memory of school children.

## Zinc

One milk slice serving, on average, supplied 0.3 mg Zn (8.95 mg kg$^{-1}$ ± ± 2.44), which covered nearly 6% of the requirement (5 mg) of children aged 4-6 for that element (Table 4). The content of Zn in cereal bars in the study of Agbaje et al. (2014) ranged from 29.76 to 50.95 mg kg$^{-1}$, which is higher than we measured. Dried apricot-date bars also contained more Zn (on average 28.4 mg kg$^{-1}$) than the milk slices in our study (Rehman et al. 2012). In contrast, on average, high-protein cereal bars (Padmashree et al. 2012) and flaxoat nutty bars (Padmashree et al. 2013) contained 2.8 mg Zn kg$^{-1}$ and 2.48 mg Zn kg$^{-1}$. The supply of Zn exceeded standard levels in the diet of 3-year-olds (6.14 mg ± 1.19) and 4-6-olds (6.38 mg ± 1.13) in the study conducted by Zyśk et al. (2020). These authors also found a positive correlation between the level of cognitive development and the intake of Zn by children aged 4-6. Zinc deficiency can impair children's cognitive processes and motor function and increase the risk of hyperactivity and depression (Anjos et al. 2013). Fuglestad et al. (2016) found that a deficiency of Zn is associated with memory impairment in children and affects their neurodevelopment.

## Coverage of Ca requirement by milk slices and cow's milk

Milk slices are advertised as snacks rich in milk cream, ideal for consumption during playtime, between meals, and after school. Their packaging shows a jug of white liquid, and the list of ingredients and the front label mention milk, which all create associations with Ca. Figure 2 presents the content of Ca in 15 analysed bars. The values were compared with the content of Ca in one glass (250 ml) of cow's milk, covering 30% of the daily Ca requirement of a child aged 4-6 (Kunachowicz et al. 2020) and being a good source of Ca in the diet of children (Jarosz et al. 2020). The highest Ca levels were found in bars nos 4 and 7 (>60 mg/serving); however, compared with

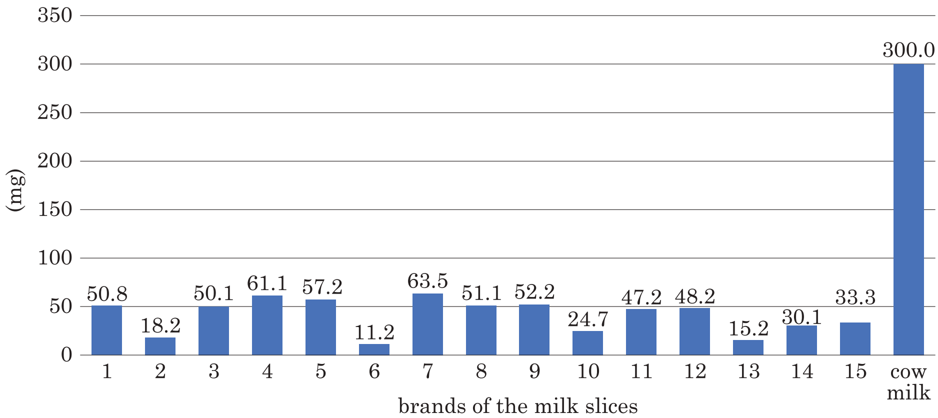


Fig 2. Comparison of Ca content in 1 package of milk slices with Ca content in 1 glass (250 ml) of cow's milk

milk, they corresponded to 20% of supplied Ca only. In contrast, the lowest Ca content was measured in bars 2, 6 and 13 (<20 mg/serving), which accounts for about 3-6% compared to the content of Ca in cow's milk. Differences in its content in milk slices and milk led to the conclusion that the analysed bars are not a good source of Ca in children's diets. In addition, milk slices are a source of added sugar in children's diets since they are rich in sugar and one milk slice supplies about 10 g of monosaccharides. The NHANES 2009-2014 study implies that the increasing consumption of added sugar also increases insufficient intake of Ca, Mg and vitamin D by children and young people in the USA (Fulgoni et al. 2019, 2020). Therefore, parents who wish to buy a valuable snack for their kids but have insufficient nutritional knowledge can misinterpret milk slice commercials and make incorrect food choices.

## Coverage of demand for selected minerals with second breakfast and afternoon snack

Assuming five meals a day, the snack served to children should constitute 10% of the energy value of the diet in the second breakfast and 15% in the afternoon snack (Charzewska 2011). Milk slices are snacks in children's diets consumed mainly for second breakfast and afternoon snack during the day. Coverage of the demand for Ca, Mg, K, Na, Fe, Cu and Zn with milk slices as second breakfast and afternoon snack is presented in Table 5. A portion of a milk slice eaten for second breakfast and afternoon

Table 5

Coverage of demand for selected minerals with second breakfast and afternoon snack

| Minerals | Demand with second breakfast (10% of daily demand) (mg) | Coverage of demand with second breakfast (%) | Demand with afternoon snack (15% of daily demand) (mg) | Coverage of demand with afternoon snack (%) |
|---|---|---|---|---|
| Ca | 100 | 40.9 | 150 | 27.3 |
| Mg | 13 | 125.4 | 19.5 | 83.6 |
| K | 110 | 106.9 | 165 | 71.3 |
| Na | 100 | 91.8 | 150 | 61.2 |
| Fe | 1.0 | 80.0 | 1.5 | 53.3 |
| Cu | 0.04 | 175 | 0.06 | 116.7 |
| Zn | 0.5 | 58.0 | 0.75 | 38.7 |

snack would cover the needs of a child aged 4-6 for Cu to the greatest extent (175% and 116.7%, respectively), and for Ca to the smallest extent (40.9% and 27.3%, respectively).

# CONCLUSIONS

1. An average milk slice serving covered the requirement for Cu to the highest extent (17.9%) and that for Ca to the lowest extent (4.1%).

2. Milk slices are not a good source of minerals, particularly of Ca, in the diet of pre-schoolers; they cannot replace a serving of milk.

3. Correct supply of minerals significantly affects the child's psychosomatic development. Children should be encouraged to consume low-processed snacks, preferably wholegrain and bran-enriched ones since a serving of such cereals supplies more Ca and Mg to young bodies while keeping the Na supply low.

4. It is worth educating parents that the Dietary Reference Values placed on milk slices packaging applies to an average adult (8400 kJ/2000 kcal) and do not reflect the nutrients' demand of children, which may be misleading.

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## 11. Oświadczenia doktoranta oraz współautorów dotyczące ich wkładu w przygotowanie opublikowanych prac naukowych

Lublin, 12.01.2026 r.

mgr Karolina Jachimowicz-Rogowska
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**Technologia Żywności i Żywienia**
**Uniwersytetu Przyrodniczego w Lublinie**

**Oświadczenie o współautorstwie**

*Niniejszym oświadczam, że w pracach:*

**P1.** Jachimowicz-Rogowska K., Winiarska-Mieczan A. (2023). Initiatives to reduce the content of sodium in food products and meals and improve the population's health. *Nutrients*, 15(10), 2393.

*Mój wkład w publikację obejmował: opracowanie koncepcji pracy, przeprowadzenie przeglądu literatury, opracowanie tabel i schematów, przygotowanie pierwszej wersji manuskryptu, pełnienie funkcji autora korespondencyjnego, przygotowanie i redakcję odpowiedzi na uwagi recenzentów.*

**P2.** Jachimowicz K., Winiarska-Mieczan A., Baranowska-Wójcik E., Bąkowski M. (2021). Pasta as a source of minerals in the diets of Poles; effect of culinary processing of pasta on the content of minerals. *Foods*, 10(9), 2131.

*Mój wkład w publikację obejmował: opracowanie koncepcji pracy, przeprowadzenie doświadczenia, przygotowanie prób do analiz laboratoryjnych, wykonanie analizy statystycznej, interpretację wyników, opracowanie tabel, przygotowanie pierwszej wersji manuskryptu, pełnienie funkcji autora korespondencyjnego, przygotowanie i redakcję odpowiedzi na uwagi recenzentów.*

**P3.** Jachimowicz-Rogowska K., Winiarska A., Szwajgier D., Baranowska-Wójcik E. (2025). The effect of pasta cooking method (unsalted versus salted water) on sodium absorption: an in vitro digestion study. *International Journal of Food Science & Technology*, 60(2), vvaf134.

*Mój wkład w publikację obejmował: udział w realizacji doświadczenia, wykonanie analizy statystycznej, interpretację wyników, opracowanie tabel, przygotowanie pierwszej wersji* *manuskryptu, pełnienie funkcji autora korespondencyjnego, przygotowanie i redakcję odpowiedzi na uwagi recenzentów.*

**P4.** Jachimowicz-Rogowska K., Winiarska A. Czernecki T. (2025). Bread consumed in recommended portions does not provide excessive amounts of sodium and salt in children's diet. *Scientific Reports*, 15, 20638

*Mój wkład w publikację obejmował: opracowanie koncepcji pracy, dostarczenie materiału badawczego, zaplanowanie i przeprowadzenie doświadczenia, wykonanie analizy statystycznej, interpretację wyników, opracowanie tabel i wykresów, przygotowanie pierwszej wersji manuskryptu, pełnienie funkcji autora korespondencyjnego, przygotowanie i redakcję odpowiedzi na uwagi recenzentów.*

**P5.** Jachimowicz-Rogowska K., Winiarska A., Dobosz A., Czernecki T. (2025). Sweet-tasting cereal products as a source of sodium and salt in children's diets. *Food Additives & Contaminants: Part A*, 1–11.

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Karolina Jachimowicz-Rogowska
*czytelny podpis*

Lublin, 12.01.2026 r.

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*Mój wkład w publikację obejmował: nadzór merytoryczny w opracowaniu koncepcji, opracowanie schematów, analizę formalną.*

**P2.** Jachimowicz K., Winiarska-Mieczan A., Baranowska-Wójcik E., Bąkowski M. (2021). Pasta as a source of minerals in the diets of Poles; effect of culinary processing of pasta on the content of minerals. *Foods*, 10(9), 2131.

*Mój wkład w publikację obejmował: nadzór merytoryczny w opracowaniu koncepcji, udział w planowaniu oraz realizacji doświadczenia, analizę formalną.*

**P3.** Jachimowicz-Rogowska K., Winiarska A., Szwajgier D., Baranowska-Wójcik E. (2025). The effect of pasta cooking method (unsalted versus salted water) on sodium absorption: an in vitro digestion study. *International Journal of Food Science & Technology*, 60(2), vvaf134.

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*Mój wkład w publikację obejmował: nadzór merytoryczny w opracowaniu koncepcji, dostarczenie materiału badawczego, udział w planowaniu doświadczenia, opracowanie tabel i wykresów, analizę formalną.*

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Anna Winiarska
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*czytelny podpis*

Lublin, 12.01.2026 r.

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Ewa Baranowska-Wójcik
……………………………………………
*czytelny podpis*

Lublin, 12.01.2026 r.

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*Mój wkład w publikację obejmował: dostarczenie materiału badawczego, przygotowanie prób do analiz laboratoryjnych.*

Tomasz Czernecki
..............................................................
*czytelny podpis*

Lublin, 12.01.2026 r.

prof. dr hab. Dominik Szwajgier
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*Mój wkład w publikację obejmował: przygotowanie i redakcję odpowiedzi na uwagi recenzentów, udział w przygotowaniu ostatecznej wersji manuskryptu.*

Domh Szyf
................................................
*czytelny podpis*

Lublin, 12.01.2026 r.

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Pracownia Analizy Pasz i Materiału Biologicznego
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*Mój wkład w publikację obejmował: przygotowanie prób do analiz laboratoryjnych.*

Agnieszka Dobosz
...............................................................
*czytelny podpis*

Lublin, 12.01.2026 r.

dr inż. Maciej Bąkowski
Zakład Żywienia Zwierząt i Paszoznawstwa
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*Mój wkład w publikację obejmował: opracowanie wykresów.*

Bąkowski
.................................................................
*czytelny podpis*

Lublin, 12.01.2026 r.

prof. dr hab. Małgorzata Kwiecień
Zakład Żywienia Zwierząt i Paszoznawstwa
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*Mój wkład w publikację obejmował: nadzór merytoryczny w opracowaniu koncepcji, opracowanie założeń metodologicznych.*

Małgorzata Kwiecień
.................................................
*czytelny podpis*

# 12. Życiorys naukowy, wykaz osiągnięć, dane bibliograficzne

## Wykształcenie

**2020-2021** **Szkoła Doktorska Uniwersytetu Przyrodniczego w Lublinie**
Proponowany tytuł rozprawy doktorskiej: „Ocena składu chemicznego produktów zbożowych preferowanych przez dzieci w wieku przedszkolnym i szkolnym oraz analiza wpływu na ich rozwój i stan zdrowia"; rezygnacja z dalszego kształcenia w Szkole Doktorskiej złożona dn. 07.07.2021 r. z powodu zatrudnienia na stanowisku asystenta w Zakładzie Bromatologii i Fizjologii Żywienia Instytutu Żywienia Zwierząt i Bromatologii Uniwersytetu Przyrodniczego w Lublinie
Promotor: dr hab. Anna Winiarska, prof. uczelni
Promotor pomocniczy: dr hab. Ewa Baranowska-Wójcik, prof. uczelni

**2018-2020** **Kierunek: Dietetyka**
**Wydział Nauk o Żywności i Biotechnologii**
**Uniwersytet Przyrodniczy w Lublinie**
Tytuł pracy magisterskiej: „Weryfikacja teoretycznego zapotrzebowania energetycznego młodych kobiet o prawidłowej masie ciała za pomocą ergospirometrii"
Promotor: prof. dr hab. Paweł Glibowski

**2015-2018** **Kierunek: Dietetyka**
**Wydział Nauk o Żywności i Biotechnologii**
**Uniwersytet Przyrodniczy w Lublinie**
Tytuł pracy licencjackiej: „*Anorexia nervosa* jako najczęściej występujące zaburzenie odżywiania wśród dziewcząt i młodych kobiet"
Promotor: dr hab. Małgorzata Kostecka, prof. uczelni

## Nagrody i wyróżnienia

1) tytuł – Specjalista Przyjazny Dzieciom – uzyskany za pozytywne ukończenie egzaminu końcowego z wynikiem 80% podczas V Kongresu Pediatryczno-Żywieniowego (nr dyplomu: K308/23), 18-19.11.2023 r.
2) II miejsce – artykuł popularnonaukowy: **Jachimowicz, K.** Czy reklamy telewizyjne wpływają na wybory żywieniowe dzieci? Ogólnopolski Konkurs „Popularyzator Dietetyki 2020", 17.11.2020 r., Uniwersytet Medyczny im. Karola Marcinkowskiego w Poznaniu
3) wyróżnienie – poster: **Jachimowicz, K.**; Roman, K.; Lipiec, Z. *Ocena wartości energetycznej i odżywczej diet szpitalnych na oddziałach ginekologiczno-położniczych.* I Ogólnopolska Konferencja Naukowa „Naukowo o Żywieniu", 18.05.2019 r., Uniwersytet Przyrodniczy w Lublinie
4) II miejsce – wystąpienie ustne: **Jachimowicz, K.** *Kuchnia lubelska – wartość odżywcza potraw w kontekście ryzyka występowania chorób dietozależnych.* III Ogólnopolska Konferencja Naukowa „Żywność-zdrowie-technologia-dystrybucja" pt. „Żywienie różnych grup wiekowych w turystyce i sporcie", 21.03.2019 r., Uniwersytet w Siedlcach
5) III miejsce – wystąpienie ustne: **Jachimowicz, K.** *Eating green – zielone światło dla nowatorskiego podejścia do zapobiegania i leczenia chorób cywilizacyjnych.* V Ogólnopolska Konferencja Młodych Naukowców Nauk Przyrodniczych „Wkraczając w świat nauki 2018", 20-21.09.2018 r., Uniwersytet Ekonomiczny we Wrocławiu
6) III miejsce – konkurs „Interdyscyplinarne rozwiązania" w ramach projektu „Drabina Kompetencji – integracja kluczem do rozwoju młodych naukowców", 24.11.2017 r., Lubelski Park Naukowo Technologiczny w Lublinie S.A.

## Projekty badawcze

(wykonawca we wszystkich poniższych projektach)

- Projekt badawczy *„Prawidłowe żywienie kobiet w ciąży i dietoprofilaktyka cukrzycy – kompleksowa opieka dietetyka"*; MNiSW Nauka dla Społeczeństwa II, nr projektu: NdS-II/SP/0443/2024/01; stanowisko w projekcie: dietetyk prowadzący poradnictwo dietetyczne; okres: 15.10.2024 r. – 14.10.2027 r.

- Projekt *„Przetwórstwo rolno-spożywcze w gospodarstwie rolnym”*; PROW 2014-2020 – Minister Rolnictwa i Rozwoju Wsi, ARMD.WZ.24.197; prowadzenie zajęć praktycznych z uczestnikami studiów podyplomowych pt. „Przetwórstwo rolno-spożywcze w gospodarstwie rolnym” z modułu „Żywność, żywienie a zdrowie człowieka”; okres: 12.10.2024 r. – 28.06.2025 r.
- Projekt badawczy *„Żywienie człowieka i dietetyka – w nauce i praktyce”*; stanowisko w projekcie: członek zespołu badawczego; okres: sierpień 2021 r. – styczeń 2022 r.
- Projekt badawczy *„Opracowanie i wdrożenie pilotażowe produktów nutraceutycznych o zaprogramowanych właściwościach prozdrowotnych w warunkach gospodarki obiegu zamkniętego”*; POIR.01.01.01-00-2204/20, nr projektu: VKT/PB-SS-A/19; stanowisko w projekcie: specjalista ds. naukowych; okres: 01.12.2021 r. – 30.09.2022 r.
- Projekt edukacyjno-badawczy *„ABC Zdrowego Żywienia”* realizowany we współpracy SGGW, UP w Lublinie i innych ośrodków akademickich, pod patronatem Ministra Edukacji Narodowej i Ministra Zdrowia; okres realizacji zadań: 07.11.2017 r. – 11.12.2017 r.

## Czynny udział w konferencjach naukowych

### Referaty wygłoszone na konferencjach:

1) **Jachimowicz-Rogowska K.** *Zasady żywienia dzieci i młodzieży w aspekcie zapobiegania chorobie próchnicowej.* IX Konferencja Naukowo-Szkoleniowa Stomatologii Dziecięcej organizowanej przez Polskie Towarzystwo Stomatologii Dziecięcej oraz Uniwersyteckie Centrum Stomatologii WUM, 27-28.09.2024 r., Warszawa
2) **Jachimowicz-Rogowska K.**, Kolasa K., Gutowska G., Kostecka M. *Wpływ pandemii COVID-19 na nawyki żywieniowe dzieci.* IX Ogólnopolska Konferencja Naukowa : Żywność - Żywienie - Dietetyka „Żywienie dzieci w/po pandemii", 17-18.11.2022 r., Częstochowa
3) **Jachimowicz K.**, Winiarska-Mieczan A. Mleczne kanapki jako źródło składników mineralnych i metali toksycznych w diecie dzieci w wieku przedszkolnym. III Konferencja Naukowa „Nauka o zbożach – osiągnięcia i perspektywy”, 22-23.09.2022 r., Lublin

4) **Jachimowicz K.**, Burczaniuk K., Sagan M., Bąkowski M. *Stosowanie żywności jako formy nagradzania i/lub karania dzieci w wieku przedszkolnym.* Ogólnopolska Konferencja Doktorantów Środowisko – Roślina – Zwierzę – Produkt, 15.04.2021 r., Lublin
5) **Jachimowicz K.** *Intake of calcium by pre-school children.* Ogólnokrajowa Konferencja Naukowa "Młody Naukowiec Część IV – Nauki interdyscyplinarne", 12-13.09.2019 r., Kraków
6) **Jachimowicz K.** *Kuchnia lubelska – wartość odżywcza potraw w kontekście ryzyka występowania chorób dietozależnych.* III Ogólnopolska Konferencja Naukowa „Żywność-zdrowie-technologia-dystrybucja" pt. „Żywienie różnych grup wiekowych w turystyce i sporcie", 21.03.2019 r., Siedlce
7) **Jachimowicz K.** *Nieśmiertelność staropolskich przypraw – korzystny wpływ na zdrowie człowieka.* III Ogólnopolska Konferencja Naukowa „Żywność-zdrowie-technologia-dystrybucja" pt. „Żywienie różnych grup wiekowych w turystyce i sporcie", 21.03.2019 r., Siedlce
8) **Jachimowicz K.** *Intake and supplementation of vitamin D by pre-school children.* Ogólnokrajowa Konferencja Naukowa "Młody Naukowiec Część IV – Nauki interdyscyplinarne", 01-02.02.2019 r., Kraków
9) **Jachimowicz K.** *Eating green – zielone światło dla nowatorskiego podejścia do zapobiegania i leczenia chorób cywilizacyjnych.* V Ogólnopolska Konferencja Młodych Naukowców Nauk Przyrodniczych „Wkraczając w świat nauki 2018", 20-21.09.2018 r., Wrocław
10) **Jachimowicz K.**, Głaszewska K., Banach K. *Wpływ wybranych składników zawartych w żywności na prawidłową pracę mózgu człowieka.* Rolnictwo - żywność - zdrowie: V Forum Młodych Przyrodników, 26.05.2018 r., Lublin
11) **Jachimowicz K.** *Rola naturalnych składników żywności w chemoprewencji raka jelita grubego.* III Ogólnopolska Konferencja „Zdrowa Opolszczyzna", 07.12.2017 r., Opole
12) **Jachimowicz K.** *Hormonalna regulacja uczucia głodu i sytości.* Rolnictwo - żywność - zdrowie: IV Forum Młodych Przyrodników, 27.05.2017 r., Lublin

**Postery zaprezentowane na konferencjach:**

1) **Jachimowicz-Rogowska K.**, Winiarska A. *Organoleptic assessment of traditional and artisan bread.* 4th International PhD Students' Conference: Environment-Plant-

Animal-Product (I-SDUPL), 09.04.2025 r., Lublin

2) **Jachimowicz-Rogowska K.**, Winiarska A. *Wpływ spożycia oleju z wiesiołka na stan skóry*. II Ogólnopolska Konferencja Naukowa „Naturalne surowce lecznicze i kosmetyczne", 18-19.03.2025 r., Lublin
3) **Jachimowicz-Rogowska K.**, Winiarska-Mieczan A., Tymczyna L., Chmielowiec-Korzeniowska A., Czernecki T., Banach M., Potrzebski D. *Wpływ beta-glukanów na zdrowie człowieka.* 46. Międzynarodowe Seminarium Naukowo-Techniczne „Chemistry for Agriculture", 20-23.11.2022 r., Karpacz
4) **Jachimowicz K.** *Analiza preferencji konsumenckich studentów na rynku ryb i przetworów rybnych.* XIV Interdyscyplinarna Konferencja Naukowa TYGIEL 2022 „Interdyscyplinarność kluczem do rozwoju", 24-27.03.2022 r., Lublin
5) **Jachimowicz K.**, Roman K., Lipiec Z. *Ocena wartości energetycznej i odżywczej diet szpitalnych na oddziałach ginekologiczno-położniczych.* I Ogólnopolska Konferencja Naukowa „Naukowo o Żywieniu", 18.05.2019 r., Lublin
6) **Jachimowicz K.**, Aleksandrowicz I. *Analiza świadomości dziewcząt w wieku licealnym na temat niebezpieczeństwa występowania anoreksji psychicznej.* IX Ogólnopolska Konferencja Dietetyki Congressus Dietetica, 05-06.04.2019 r., Łódź
7) **Jachimowicz K.**, Konarska J., Kostecka, M. *Plastic products containing alternatives to bisphenol A (BPA) – are they certainly better for human health?* The 3rd International Conference „Human ecology", 19-20.06.2018 r., Lublin
8) **Jachimowicz K.**, Górska A. *Anoreksja=niepłodność? Związek utraty masy ciała z zaburzeniami hormonalnymi wśród kobiet.* Rolnictwo - żywność - zdrowie: V Forum Młodych Przyrodników, 26.05.2018 r., Lublin

## Aktywność popularyzatorska

1) Przygotowanie i zrealizowanie autorskich warsztatów żywieniowych pt. „Mój Talerz Zdrowego Żywienia" dla dzieci uczęszczających do oddziałów przedszkolnych oraz uczniów klas 1-3 Szkoły Podstawowej im. bł. Jana Pawła II w Siedliskach Drugich dnia 23.09.2025 r.
2) Udział w audycji radiowej razem ze studentką dietetyki w ramach cyklu programów o zdrowej diecie w Nowe Radio; 30.05.2025 r., Lublin
3) Wygłoszenie prelekcji o charakterze popularnonaukowym na wydarzeniu w ramach projektu „Produkty mleczne na szlakach kulinarnych" realizowanego przez Stowarzyszenie Polska Ekologia, finansowanego z Funduszu Promocji Mleka;

28.09.2024 r., Szczebrzeszyn

4) Autorstwo i przeprowadzenie szkolenia online dla dietetyków pt. „Insulinooporność u dzieci i nastolatków – coraz częstszy problem w gabinecie dietetyka” na platformie www.kcalmar.com w ramach szkoleń Instytutu Edukacji Żywieniowej 2023; opublikowano 22.12.2023 r.
5) Przygotowanie i zrealizowanie autorskich warsztatów żywieniowych pt. „Zdrowe odżywianie w szkolnym wydaniu” dla uczniów w Szkole Podstawowej Sióstr Urszulanek UR w Lublinie; 20.10.2022 r.
6) Organizacja i udział w projektach realizowanych w ramach Lubelskiego Festiwalu Nauki w latach 2017, 2018, 2021, 2022
7) Aktywny udział w pracach Studenckiego Koła Naukowego Dietetyków w latach 2015 – 2020
8) Autorstwo kilkuset publikacji popularnonaukowych na portalach internetowych: Zdrowe Dziecko, Zdrowe Rozwiązania, Takie Zdrowe i Journal of Nutrilife oraz w czasopismach: Food Forum i Naturoterapia w praktyce.

## Aktywność organizacyjna

1) Opiekun studentów kierunku Dietetyka na praktykach zawodowych w Poradni Dietetycznej Uniwersytetu Przyrodniczego w Lublinie w latach 2021 – 2022
2) Członek Komitetu Organizacyjnego podczas I Ogólnopolskiej Konferencji Naukowej „Naukowo o Żywieniu”, Uniwersytet Przyrodniczy w Lublinie, 18.05.2019 r.
3) Współorganizacja V i VI edycji Festiwalu Przedszkolaka „Jem kolorowo, ale zdrowo!” w latach 2018 i 2019 w ramach działalności w Studenckim Kole Naukowym Dietetyków
4) Członek Wydziałowej Komisji Wyborczej (Wydział Nauk o Żywności i Biotechnologii) w latach 2018 – 2020
5) Członek Wydziałowej Rady Samorządu Studenckiego Uniwersytetu Przyrodniczego w Lublinie (Wydział Nauk o Żywności i Biotechnologii) w okresie październik 2017 – lipiec 2020

Lublin, 19.01.2026 r.

Biblioteka Główna UP w Lublinie
Bibliografia Publikacji Pracowników Uniwersytetu Przyrodniczego

Raport autora – mgr Karolina Jachimowicz-Rogowska

## 1. Publikacje w czasopismach naukowych

### 1.1. Publikacje w czasopiśmie naukowym posiadającym Impact Factor IF

| Lp | Opis bibliograficzny | IF | Pkt. MNiSW |
|---|---|---|---|
| 1. | Bread consumed in recommended portions does not provide excessive amounts of sodium and salt in children's diet. [AUT. KORESP.] KAROLINA JACHIMOWICZ-ROGOWSKA, [AUT.] ANNA WINIARSKA, TOMASZ CZERNECKI. *Sci. Rep. (Nat. Publ. Group)* 2025 Vol.15 Article number: 20638, il., bibliogr. sum. DOI: 10.1038/s41598-025-06824-x | 3,900 | 140,00 |
| 2. | Effect of cultivar and the number of harvests on the feed value, protein fractions and nutrient digestibility of *Festulolium braunii* forage in young cattle. [AUT. KORESP.] M. BORSUK-STANULEWICZ, [AUT.] C. PURWIN, P. POGORZELSKA-PRZYBYŁEK, BARBARA STEFAŃSKA, ANNA WINIARSKA-MIECZAN, K. JACHIMOWICZ-ROGOWSKA. *J. Anim. Feed Sci.* 2025 Vol. 34 Issue 3 s. 461-475, il., bibliogr., sum. DOI: 10.22358/jafs/204855/2025 | 1,500 | 100,00 |
| 3. | The effect of pasta cooking method (unsalted versus salted water) on sodium absorption: an *in vitro* digestion study. [AUT. KORESP.] KAROLINA JACHIMOWICZ-ROGOWSKA, [AUT.] ANNA WINIARSKA, DOMINIK SZWAJGIER, EWA BARANOWSKA-WÓJCIK. *Int. J. Food Sci. Technol.* 2025 Vol. 60 Iss. 2 Article numer: vvaf134, il., bibliogr., sum. DOI: 10.1093/ijfood/vvaf134 | 3,100 | 70,00 |
| 4. | Fatty acid profile and dietary value of thigh meat of broiler chickens receiving mineral or organic forms of Zn. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] MAŁGORZATA KWIECIEŃ, CEZARY PURWIN, KAROLINA JACHIMOWICZ-ROGOWSKA, MARTA BORSUK-STANULEWICZ, PAULINA POGORZELSKA-PRZYBYŁEK, BOŻENA KICZOROWSKA. *Animals* 2024 | 2,700 | 100,00 |

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| | Vol. 14 Issue 8 Article number 1156, il., bibliogr., sum. DOI: 10.3390/ani14081156 | | |
| 5. | Polyphenols influence the development of endometrial cancer by modulating the gut microbiota. [AUT.] EWA BARANOWSKA-WÓJCIK, [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] PIOTR OLCHA, MAŁGORZATA KWIECIEŃ, KAROLINA JACHIMOWICZ-ROGOWSKA, ŁUKASZ NOWAKOWSKI, ANDRZEJ MITURSKI, KRZYSZTOF GAŁCZYŃSKI. *Nutrients* 2024 Vol. 16 Issue 5 Article number 681, il., bibliogr., sum. DOI: 10.3390/nu16050681 | 5,000 | 140,00 |
| 6. | Regular consumption of green tea as an element of diet therapy in drug-induced liver injury (DILI). [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] KAROLINA JACHIMOWICZ-ROGOWSKA, MAŁGORZATA KWIECIEŃ, MARTA BORSUK-STANULEWICZ, AGNIESZKA TOMCZYK-WARUNEK, EWA STAMIROWSKA-KRZACZEK, CEZARY PURWIN, MAŁGORZATA STRYJECKA, MARZENA TOMASZEWSKA. *Nutrients* 2024 Vol. 16 Issue 17 Article number: 2837, il., bibliogr., sum. DOI: 10.3390/nu16172837 | 5,000 | 140,00 |
| 7. | The effect of cadmium and lead on living organisms – transport, accumulation, metabolism. [AUT.] MACIEJ BĄKOWSKI, ANNA WINIARSKA-MIECZAN, MAŁGORZATA KWIECIEŃ, ROBERT KRUSIŃSKI, KAROLINA JACHIMOWICZ-ROGOWSKA, TWARUŻEK MAGDALENA, DANUTA GROBELSKA. *J. Elem.* 2024 Vol. 29 Nr 1 s. 311-329, il., bibliogr., sum. DOI: 10.5601/jelem.2023.28.3.3098 | 0,700 | 70,00 |
| 8. | Anti-inflammatory, antioxidant, and neuroprotective effects of polyphenols—polyphenols as an element of diet therapy in depressive disorders. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] MAŁGORZATA KWIECIEŃ, KAROLINA JACHIMOWICZ- ROGOWSKA, JANINE DONALDSON, EWA TOMASZEWSKA, EWA BARANOWSKA-WÓJCIK. *Int. J. Mol. Sci.* 2023 Vol. 24 Issue 3 Article number: 2258, il., bibliogr., sum. DOI: 10.3390/ijms24032258 | 4,900 | 140,00 |
| 9. | Assessment of the chemical composition and nutritional quality of breast muscle from broiler chickens receiving various levels of Fe glycine chelate. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] MAŁGORZATA KWIECIEŃ, KAROLINA JACHIMOWICZ-ROGOWSKA, SVITLANA KISLOVA, ZWENYSLAWA ZASADNA, DYMYTRO YANOVYCH. | 3,300 | 140,00 |

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| | *Agriculture* 2023 Vol. 13 issue 7 Article number: 1455, il.bibliogr.,sum. DOI: 10.3390/agriculture13071455 | | |
| 10. | Bioactive compounds, antibiotics and heavy metals: Effects on the intestinal structure and microbiome of monogastric animals – a non-systematic review. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] MAŁGORZATA KWIECIEŃ, KAROLINA JACHIMOWICZ-ROGOWSKA, SIEMOWIT MUSZYŃSKI, EWA TOMASZEWSKA. *Ann. Anim. Sci.* 2023 Volume 23 Issue 2 s. 289- 313, il., bibliogr. sum. DOI: 10.2478/aoas-2022-0057 | 1,800 | 200,00 |
| 11. | Cadmium and lead concentration in drinking instant coffee, instant coffee drinks and coffee substitutes: safety and health risk assessment. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] KAROLINA JACHIMOWICZ, SVITLANA KISLOVA, MAŁGORZATA KWIECIEŃ, ZWENYSLAWA ZASADNA, DYMYTRO YANOVYCH. *Biol. Trace Elem. Res.* 2023 Vol. 201 s. 425–434, il., bibliogr., sum. DOI: 10.1007/s12011-022-03129-2 | 3,400 | 70,00 |
| 12. | Effect of β-glucans on human health (Wpływ β-glucanów na zdrowie człowieka). [AUT.] KAROLINA JACHIMOWICZ- ROGOWSKA, ANNA WINIARSKA-MIECZAN, ANNA CHMIELOWIEC-KORZENIOWSKA, LESZEK TYMCZYNA, TOMASZ CZERNECKI, MARCIN BANACH, DANIEL POTRZEBSKI. *Przem. Chem.* 2023 T. 102 Nr 3 s. 277-286, il., bibliogr., sum. DOI: 10.15199/62.2023.3.6 | 0,300 | 100,00 |
| 13. | Effects of dietary supplementation of L-carnitine and mannan-oligosaccharides on growth performance, selected carcass traits, content of basic and mineral components in liver and muscle tissues, and bone quality in turkeys. [AUT.] MAŁGORZATA KWIECIEŃ, KAROLINA JACHIMOWICZ- ROGOWSKA, WANDA KRUPA, ANNA WINIARSKA-MIECZAN, MAGDALENA KRAUZE. *Animals* 2023 Vol. 13 Issue 4 Article number: 770, il., bibliogr. sum. | 2,700 | 100,00 |
| 14. | Initiatives to reduce the content of sodium in food products and meals and improve the population's health. [AUT.] KAROLINA JACHIMOWICZ-ROGOWSKA, ANNA WINIARSKA-MIECZAN. *Nutrients* 2023 Vol. 15, Issue 10 Article number: 2393, il., bibliogr., sum. DOI: 10.3390/nu15102393 | 4,800 | 140,00 |
| 15. | Milk slices as a source of macroelements and microelements in the diet of pre-schoolers. [AUT. | 0,700 | 140,00 |

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| | KORESP.] KAROLINA JACHIMOWICZ-ROGOWSKA, [AUT.] ANNA WINIARSKA-MIECZAN, MAŁGORZATA KWIECIEŃ. *J. Elem.* 2023 Vol. 28 Nr 2 s. 349-361, il., bibliogr., sum. DOI: 10.5601/jelem.2023.28.2.2371 | | |
| 16. | The content of Cd and Pb in herbs and single-component spices used in Polish cuisine. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] KAROLINA JACHIMOWICZ, MAŁGORZATA KWIECIEŃ, ROBERT KRUSIŃSKI, SVITLANA KISLOVA, LESYA SOWIŃSKA, ZWENYSLAWA ZASADNA, DYMYTRO YANOVYCH. *Biol. Trace Elem. Res.* 2023 Vol. 201 s.3567–3581, il., bibliogr., sum. DOI: 10.1007/s12011-022-03437-7 | 3,400 | 70,00 |
| 17. | Contents of Na, K, Ca, Mg, Zn, Cu and Fe in flavoured honeys. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] MAŁGORZATA KWIECIEŃ, ANNA CHMIELOWIEC-KORZENIOWSKA, KAROLINA JACHIMOWICZ-ROGOWSKA, LESZEK TYMCZYNA, ANNA ŻEBRACKA, AGATA BIELAK. *J. Elem.* 2022 Vol. 27 Nr 4 s 917-927, il., bibliogr., sum. DOI: 10.5601/jelem.2022.27.3.2333 | 0,800 | 70,00 |
| 18. | Seasonal changes in trace-element content in the coat of Hucul horses. [AUT. KORESP.] KAROLINA JACHIMOWICZ- ROGOWSKA, [AUT.] JADWIGA TOPCZEWSKA, WANDA KRUPA, MARCIN BAJCAR, MAŁGORZATA KWIECIEŃ, ANNA WINIARSKA-MIECZAN. *Animals* 2022 Vol. 12 Issue 20 Article number: 2770, il., bibliogr. sum. DOI: 10.3390/ani12202770 | 3,000 | 100,00 |
| 19. | Tannic acid and tea prevents the accumulation of lead and cadmium in the lungs, heart and brain of adolescent male wistar rats - possible therapeutic option. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] MAŁGORZATA KWIECIEŃ, MACIEJ BĄKOWSKI, ROBERT KRUSIŃSKI, KAROLINA JACHIMOWICZ-ROGOWSKA, MARTA DEMKOWSKA-KUTRZEPA, BOŻENA KICZOROWSKA, WANDA KRUPA. *Animals* 2022 Vol. 12 Issue 20 Article number: 2838, il., bibliogr. sum. DOI: 10.3390/ani12202838 | 3,000 | 100,00 |
| 20. | The impact of herbal additives for poultry feed on the fatty acid profile of meat. [AUT. KORESP.] KAROLINA JACHIMOWICZ, [AUT.] ANNA WINIARSKA-MIECZAN, EWA TOMASZEWSKA. *Animals* 2022 Vol. 12 Issue 9 Article number: 1054, il., bibliogr. sum. DOI: 10.3390/ani12091054 | 3,000 | 100,00 |
| 21. | The role of nutritional factors in the modulation of the composition of the gut microbiota in people with | 5,900 | 140,00 |

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|---|---|---|---|
| | autoimmune diabetes. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, EWA TOMASZEWSKA, [AUT.] JANINE DONALDSON, KAROLINA JACHIMOWICZ. *Nutrients* 2022 Vol. 14, Issue 12 Article number 2498, il., bibliogr., sum. DOI: 10.3390/nu14122498 | | |
| 22. | Antioxidant, anti-inflammatory, and immunomodulatory properties of Ttea—The positive impact of tea consumption on patients with autoimmune diabetes. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, EWA TOMASZEWSKA, [AUT.] KAROLINA JACHIMOWICZ. *Nutrients* 2021 Vol. 13, Issue 11 Article number:3972, il., bibliogr., sum. DOI: 10.3390/nu13113972 | 6,706 | 140,00 |
| 23. | Evaluation of consumer safety of Polish honey—the content of Cd and Pb in multifloral, monofloral and honeydew honeys. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] BARBARA WARGOCKA, KAROLINA JACHIMOWICZ, EWA BARANOWSKA-WÓJCIK, KATARZYNA KWIATKOWSKA, MAŁGORZATA KWIECIEŃ. *Biol. Trace Elem. Res.* 2021 Vol 199 Issue 11 s. 4370–4383, il., bibliogr., sum. DOI: 10.1007/s12011-020-02535-8 | 4,081 | 70,00 |
| 24. | Pasta as a source of minerals in the diets of Poles; effect of culinary processing of pasta on the content of minerals. [AUT. KORESP.] KAROLINA JACHIMOWICZ, [AUT.] ANNA WINIARSKA-MIECZAN, EWA BARANOWSKA-WÓJCIK, MACIEJ BĄKOWSKI. *Foods* 2021 Vol. 10 Issue 9 Article number: 2131, il., bibliogr., sum. DOI: 10.3390/foods10092131 | 5,561 | 100,00 |
| 25. | The effect of Cu, Zn and Fe chelates on the antioxidative status of thigh meat of broiler chickens. [AUT. KORESP.] A. WINIARSKA-MIECZAN, [AUT.] M. KWIECIEŃ, T. MIECZAN, K. KWIATKOWSKA, K. JACHIMOWICZ. *Animal* 2021 Vol. 15 Issue 10 Article number: 100367, il., bibliogr., sum. DOI: 10.1016/j.animal.2021.100367 | 3,730 | 200,00 |
| 26. | The impact of Zn, Cu and Fe C chelates on the fatty-acid profile and dietary value of broiler-chicken thigh meat. [AUT. KORESP.] ANNA WINIARSKA-MIECZAN, [AUT.] KAROLINA JACHIMOWICZ, MAŁGORZATA KWIECIEŃ, SVITLANA KISLOVA, EWA BARANOWSKA-WÓJCIK, ZWENYSLAWA ZASADNA, DYMYTRO YANOVYCH, EDYTA KOWALCZUK-VASILEV. *Animals* 2021 Vol. 11 Issue11 Article number: 3115, il., bibliogr. sum. DOI: 10.3390/ani11113115 | 3,231 | 100,00 |

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| | Suma: | 86,209 | 2980,00 |

## 1.2 Publikacja w czasopiśmie naukowym nieposiadającym IF

| Lp | Opis bibliograficzny | Pkt. MNiSW |
|---|---|---|
| 1. | Amigdalina – analiza jej toksycznego i antynowotworowego działania (Amygdalin – analysis of its toxic and anticancer effects). [AUT.] ANNA WINIARSKA-MIECZAN, MAŁGORZATA KWIECIEŃ, KAROLINA JACHIMOWICZ-ROGOWSKA, ROBERT KRUSIŃSKI. *Journal of Animal Science, Biology and Bioeconomy* 2024 Vol. 40 Iss. 1 s. 5-13, il., bibliogr., streszcz., sum. DOI: 10.24326/jasbb.2024.5316 | 20,00 |
| 2. | Czy pandemia covid-19 wpłynęła na sposób żywienia dzieci w wieku przedszkolnym chorujących na alergie pokarmowe? (Has the covid-19 pandemic affected the nutrition of pre-school-age children with food allergies?). [AUT. KORESP.] MAŁGORZATA KOSTECKA, [AUT.] JULIANNA KOSTECKA, GABRIELA GUTOWSKA, KAROLINA JACHIMOWICZ-ROGOWSKA, KATARZYNA KOLASA, MONIKA BOJANOWSKA. *Żywn. Nauka Technol. Jakość (2016-)* 2023 Vol. 30 nr 2 (135) s. 82-95, il., bibliogr., streszcz., sum. DOI: 10.15193/zntj/2023/135/448 | 200,00 |
| 3. | Diet therapy as support for the treatment of atopic dermatitis (Dietoterapia jako wsparcie leczenia atopowego zapalenia skóry). [AUT.] EWELINA CHRZANOWSKA, ANNA WINIARSKA-MIECZAN, KAROLINA JACHIMOWICZ-ROGOWSKA. *Aesthet. Cosmetol. Med.* 2023 Vol.12 Issue 4 s. 125-131, il., bibliogr., summ. DOI: 10.52336/acm.2023.010 | 5,00 |
| 4. | Verification of the theoretical energy requirement of underweight, normal weight and overweight young women using ergospirometry (Weryfikacja teoretycznego zapotrzebowania energetycznego młodych kobiet z niedowagą, prawidłową masą ciała i nadmierną masą ciała za pomocą ergospirometrii). [AUT.] KAROLINA JACHIMOWICZ-ROGOWSKA, ANNA WINIARSKA-MIECZAN, PAWEŁ GLIBOWSKI, ILONA ALEKSANDROWICZ-NIEDZIELA, IWONA SMAGAŁA, AGATA BIELAK. *Nauki Inż. Technol.* 2023 Nr 39 s. 52-64, il., bibliogr., streszcz., sum. DOI: 10.15611/nit.2023.39.04 | 40,00 |
| 5. | The most commonly used diet supplements for hair, skin and nails in the opinion of pharmacy employees from different cities in Poland (Najczęściej stosowane suplementy diety na włosy, skórę i paznokcie w opinii pracowników aptek z różnych miast na terenie Polski). [AUT.] KAROLINA JACHIMOWICZ- ROGOWSKA, LESYA SOWIŃSKA, ANNA WINIARSKA-MIECZAN, KATARZYNA KOLASA, JULIA FABJANOWSKA. *Nauki Inż. Technol.* 2022 Nr 1 (38) s. 60-74, il., bibliogr., streszcz., sum. DOI: 10.15611/nit.2022.38.04 | 20,00 |
| 6. | Analiza jakościowa sposobu żywienia pensjonariuszy Domu Pomocy Społecznej w Lublinie. [AUT.] ANNA WINIARSKA-MIECZAN, KAMILA MUZYKA, KAROLINA JACHIMOWICZ. *Bromatol. Chem. Toksykol.* 2021 T. | 5,00 |

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| | 54 Nr 1 s. 46-56, il., bibliogr., streszcz., sum. | |
| 7. | **Inozytol oraz jego właściwości pomocne w leczeniu zaburzeń płodności.** [AUT. KORESP.] JAGODA KRUK, [AUT.] KAROLINA JACHIMOWICZ, ANNA WINIARSKA-MIECZAN. *Przem. Spoż.* 2021 T. 75 nr 3 s. 24-26, il., bibliogr., streszcz., sum. DOI: 10.15199/65.2021.7.4 | 20,00 |
| | Suma: | 310,00 |

## 2. Monografie naukowe

### 2.1 Autorstwo rozdziału monografii naukowej

| Lp | Opis bibliograficzny | Pkt. MNiSW |
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## 3. Inne

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