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Foodomics Approaches to Facilitate the Verification of the Authenticity of Foods: A Possible Strategy to Screen, Validate, and Standardize Food Matrices

Nurpudji Astuti TASLIM[1], Fahrul NURKOLIS[2], Hardinsyah HARDINSYAH[3], Vincentius Mario YUSUF[4], William Ben GUNAWAN[5], Mrinal SAMTIYA[6], Nelly MAYULU[7], Youla A. ASSA[8], Trina Ekawati TALLEI[7]

1 Division of Clinical Nutrition, Department of Nutrititon, Faculty of Medicine, Hasanuddin University, Indonesia.
2 Biological Sciences, State Islamic University of Sunan Kalijaga (UIN Sunan Kalijaga), Yogyakarta, Indonesia.
3 Applied Nutrition Division, Department of Community Nutrition, Faculty of Human Ecology, IPB University, Bogor, Indonesia.
4 Medical Programme, Faculty of Medicine, Brawijaya University, Malang, Indonesia.
5 Department of Nutrition Science, Faculty of Medicine, Diponegoro University, Semarang, Indonesia.
6 Department of Nutrition Biology, Central University of Haryana, Mahendragarh, India.
7 Department of Biology, Faculty of Mathematics and Natural Sciences, Sam Ratulangi University, Manado, Indonesia.
8 School of Medicine, Sam Ratulangi University, Manado, Indonesi

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ABSTRACT

Introduction: The complexity of globalization, including the global food trade market, has the side effect that various raw foodstuffs are vulnerable to intentional and unintentional adulteration. However, food validation and standardization approaches are still unclear and challenging and need to be explored.

Objective: Through this opinion review article, the author would like to introduce a foodomics approach (Food, -Omics) to facilitate integrated food authenticity verification through biosensors.

Method: This approach was based on literature review of potentially suitable and offers methods of Foodomics as they combine biological analysis methods spanning genomics, transcriptomics, proteomics, and metabolomics. Meanwhile, several subdisciplines of Foodomics, such as metallomics, volatomics, and lipidomics, which are considered feasible to facilitate the verification of food authenticity, are also explored and reviewed in this critical opinion.

Result: Foodomics consists of four main omics technologies, namely genomics, transcriptomics, proteomics, and metabolomics. This is an integration of promising approaches to provide standardized food matrices, thus becoming the most likely strategy to verify the authenticity of food. However, after trying to uncover this food authentication problem and provide a Foodomics approach, we felt the need for synergies in building a database capable of storing food matrices in the form of unique genes, bioactive peptides, and secondary metabolites. We hope that through this opinion review article, the target database can be formed, although databases such as MEDLINE and PubChem have provided this data facility.

Conclusion: In particular, we suggest the development of nanobiosensors that should undoubtedly be environmentally friendly and portable (making use of smartphones) and creating a cloud database capable of storing food matrices in the form of unique genes, bioactive peptides, and secondary metabolites, integrated with smartphone biosensors. Finally, as a result, the researcher tries to answer this database problem so that foodomics integrated with the database can solve the problem of detecting fraud and counterfeiting of foodstuffs.

KEYWORDS

Foodomics, Food Authenticity, Food Matrices, Food Science, Biosensor.

Correspondencia:
Nurpudji Astuti Taslim
pudji_taslim@yahoo.com

ACRONYMS AND ABBREVIATIONS

AuNP-DNA: Gold nanoparticle-DNA.

CRISPR: Clustered Regularly Interspaced Short Palindromic Repeats.

DHA: Docosahexaenoic acid.

DNA: Deoxyribonucleic acid.

EPA: Eicosapentaenoic acid.

EVOO: Extra virgin olive oil.

Foodomics: Food -omics.

GC-IMS: Gas-chromatography ion mobility spectrometry.

GNPs: Gold nanoparticle-based RNA sensors.

gRNA: A guide RNA.

HPLC-ESI-HRMS/MS: Liquid Chromatography Coupled to High-Resolution Tandem Mass Spectrometry Method.

LC-ESI MS/MS: Liquid Chromatography Electrospray Ionization Tandem Mass Spectrometric.

LC-HRMS: Liquid Chromatography High Resolution Mass Spectrometry.

LEG: Laser-engraved graphene.

MALDI-TOF/TOF MS: Matrix-assisted laser desorption/ionization time-of-flight/time-of-flight.

MEF: Metal-enhanced fluorescence.

MIP: Molecularly minted polymer-based artificial proteins.

MRM: Multiple reactions-monitoring.

mRNA: Messenger RNA.

RNA: Ribonucleic acid.

SNPs: Single nucleotide polymorphisms.

SSB: single-stranded binding.

INTRODUCTION

The complexity of globalization, in addition to having a positive impact on the economy, turns out to have side effects that are certainly undesirable. Globalized food trade markets have resulted in complex supply chains where various raw foodstuffs are vulnerable to accidental and deliberate counterfeiting. Unfortunately, the existence of many potential counterfeits of incorrect geographic origins makes the detection of fraud and counterfeiting of these foodstuffs a significant challenge. Research on the development and application of chemical fingerprinting methods to facilitate verification of food authenticity has a growing trend[1]. In the 21st century, thanks to the omics approach, researchers now face the possibility of linking food components, diet, individuals, health, and disease. Still, this broad vision requires not only the application of advanced technologies but also the ability to see problems with a different approach, a "Foodomics Approach". Foodomics is a comprehensive, high-yield approach to exploiting food science to improve human nutrition[2,3]. As mentioned above, the food validation and standardization approach remains unclear, challenging, and needs to be explored. Through this opinion review article, the author would like to introduce the foodomics (Food, -Omics) approach to facilitating integrated food authenticity verification via biosensors. This approach is potentially suitable and offers more valuable accuracy because it combines biological analysis methods that include genomics, transcriptomics, proteomics, and metabolomics. Meanwhile, several subdisciplines of Foodomics, such as metallomics, volatomics, and lipidomics which are considered feasible to facilitate the verification of foods authenticity, are also explored in this critical review opinion.

METHODS AND SEARCH STRATEGY

This study is a literature review. Search strategy utilized main keywords such as "foodomics", "omics", and other relevant keywords. The recent literature in the last 5 years (2017–2022) was collected from Medical Literature Analyses and Retrieval System Online (MEDLINE), Science Direct (SCOPUS), and Google Scholar databases.

Foodomics

Potential Applications of Genomics Methods to Validate Food Authenticity

Genomics is an interdisciplinary field of biological science focused on structure, function, evolution, mapping, and genome editing[4]. Each type of living thing has identic and distinctive DNA[5]. Therefore, genome matching is often carried out on new living beings that have not been identified through genomics by looking at the uniqueness of each type and identifying the regional origin of an organism by matching databases such as gene banks and seeing if foodstuffs have been genetically modified[6]. Here the author argues that genomics is an approach that can be used to overcome food counterfeiting or raw foodstuffs. A case study conducted a study on collecting African rice in the Suriname market and sequenced and compared its genomes of 109 genomes of accession representing the diversity of *Oryza glaberrima* or African rice[7]. Analysis of 1,649,769 single nucleotide polymorphisms (SNPs) in a grouping analysis found that Suriname samples appeared to be brothers with *Ivorian landrace* and showed no evidence of introgression from Asian rice[7]. This reveals the usefulness of genomics in understanding most of the unwritten history of diaspora community plant cultures and courses as part of the food authenticity process.

Furthermore, the application of genomics technology with electro combinations is being brought to the attention of biosensor innovations through electrochemical DNA. Over the past few years, significant efforts have been made to develop biosensing technologies in foodborne pathogens detection as unique in foods[8]. However, the cost is still too high, especially in developing countries where wide-scale applications are still hampered. The application of classic DNA markers for food authentication can explain the potential of nanobiosensors in food authentication[9]. This is the latest interest in the application of electrochemical DNA-based biosensor methods for verifying the authenticity of foods (Table 1; Figure 1).

Table 1. Foodomics and Technology Combined in its Potential as a Food Authenticity Approaches

Foodomics Type	Current Advances & Innovations	Advantages and/or Targets	Weakness /Limitations	References	Overall Future Suggested Opinion
Genomics	Single nucleotide polymorphisms (SNPs)	Genome comparison between types of foodstuffs can be done	The cost is quite exclusive and must be done using laboratory equipment	(8)	We support the development of environmentally-friendly and portable nanobiosensors, as well as the creation of a cloud database capable of storing food matrices in the form of unique genes, bioactive peptides, and secondary metabolites, which are integrated with smartphone biosensors and the development of artificial intelligence.
Genomics-Electrochemicals	Electrochemical DNA biosensors & AuNP-DNA	DNA detection of foodstuffs; Biosensors derived from nanomaterials and conventional nanomaterials	Needs the development of signal-based portables from smartphones; Challenges due to low detection levels, selectivity, mismatches detection, non-specific adsorption, signal amplification, and integration of different processes.	(8,25)	
Transcriptomics-Metallomics-Electrochemicals	Fluorescence biosensors based on single-stranded binding (SSB) protein or DNA biosensors; gRNA; CRISPR-Cas12 GNPs	A protein-based biosensor for mRNA	High selectivity, sufficient sensitivity, and stability are achieved in revealing the true detection of mRNA in foodstuffs; while food is complex, this method requires specific conditions; may lead to a false positive response, instability of GNPs	(11–14)	
Proteomics-Electrochemicals	Protein sequencer; LC-ESI-IT MS/MS -IEF; MALDI-TOF/TOF MS; MRM	Detection of specific amino acids or bioactive peptides	Can't fully identify the proteins which imply the need for specific biomarkers; A portable sequencing protein that is more applicable and affordable is needed	(18,19)	

Table 1 continuación. Foodomics and Technology Combined in its Potential as a Food Authenticity Approaches

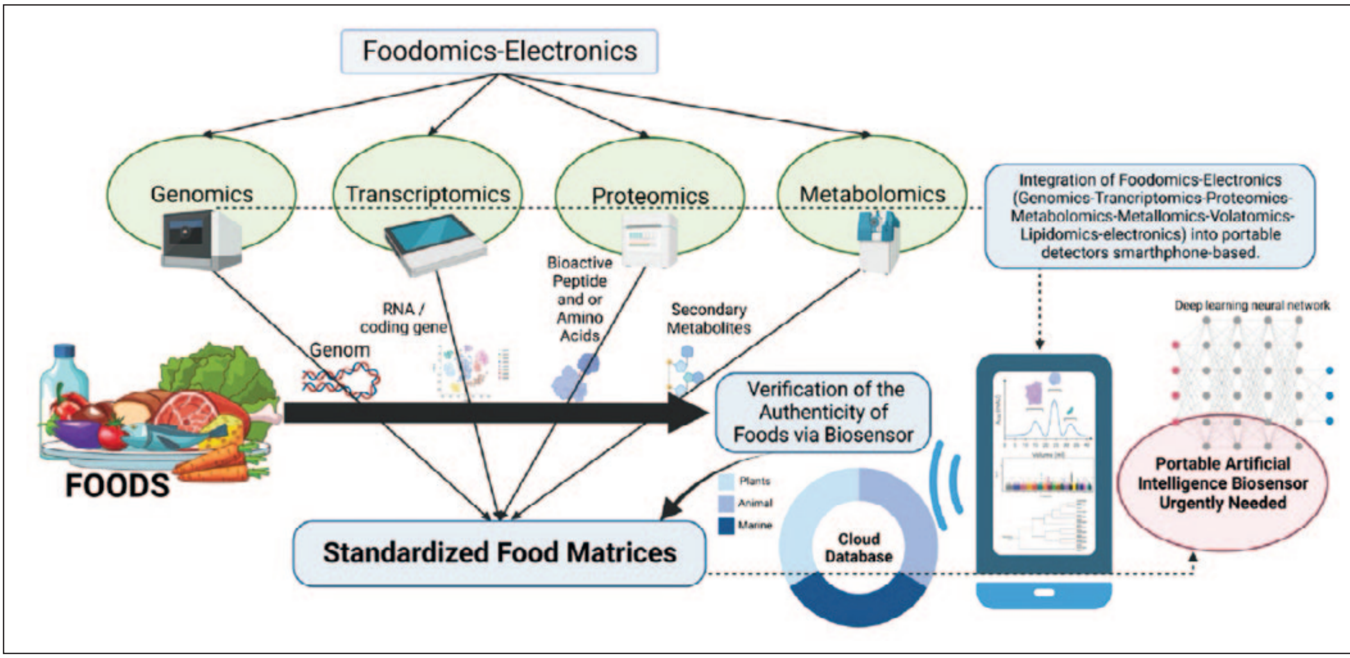
Foodomics Type	Current Advances & Innovations	Advantages and/or Targets	Weakness /Limitations	References	Overall Future Suggested Opinion
Metabolomics-Lipidomics-Volatomics	LC-HRMS	Specific secondary metabolites and fatty acids from foodstuffs can be detected	The cost is quite exclusive and must be done using laboratory equipment	(24,26)	
Metabolomics-Electrochemicals	Electrochemical biosensors; The combination or integration of mass-producible laser-engraved graphene (LEG), electrochemically synthesized redox-active nanoreporters, and molecularly minted polymer-based artificial proteins (MIPs), as well as unique in situ regeneration and calibration technologies	This technology can be applied as an authenticator through the validation of metabolites, while the portable aspect can also be industrialized	Needs signal-based development of smartphones and artificial intelligence; broader biomarkers need to be coupled with greater sensitivity	(24)	
Metabolomics-volatomics	Partial least squared discriminant analysis and support vector machine (PLS-DA-SVM) strategies; gas-chromatography ion mobility spectrometry (GC-IMS) and flash gas-chromatography electronic nose (FGC-Enose data)	Can authenticate volatile food extracts or a type of volatile, such as Extra virgin olive oil (EVOO); faster spectrum gain	Currently only applicable in industrial-scale production monitoring; analytical and chemometric efforts regarding datasets are required	(26)	

Are Transcriptomics Methods Applicable to Validate Food Authenticity?

In the previous sub, the use of genomics leans more towards DNA, but not in this transcriptomic approach through the identification of RNA in foodstuffs. Transcriptomic is a collection of RNA molecules derived from protein-coding genes expressed in biology. This is what we can use in filtering information and validating the authenticity of food through its coding genes. Once the transcripts are assembled, downstream analyses such as expression profiles, gene ontology, and path enrichment analyses can provide more insight into gene regulation. Development of new molecular approaches to detect and identify a wide diversity of species in a specific assay, exploiting the conservation, abundance, and rich phylogenetic content of ribosomal RNA in rapid fluorescent hybridization assays that do not require amplification or enzymology. This transcriptomics approach can also play an essential role in screening and validating food authenticity processes. In fact, with this technology, we can identify whether the food has been genetically modified intentionally or unintentionally. This is in line with a study about the food safety assessment of genetically engineered crops with RNA interference in food crops or crops[10].

Interestingly, the application of transcriptomics can be made portably, just like in genomics. A protein-based biosensor for mRNA that generally uses synthetic fluorescent dyes is

Figure 1. Possible Mechanisms of Foodomics Approaches to Verify the Authenticity of Foods via Biosensor and Future Directions



relatively expensive. Recent studies reported using fluorescent biosensors based on single-stranded binding (SSB) proteins, which have previously been designated as ssDNA biosensors[11,12]. Furthermore, the novel gold nanoparticle-based RNA sensors (GNPs) become approaches with colorimetric and electrochemical responses, effectively detecting illegal additives[13]. Most recently, CRISPR-Cas12, as a form of transcriptomic application, has been used as an approach to the rapid detection of halal food. The gRNA biosensor allows specific identification of the target Cyt b gene of the pork component, followed by activation of the Cas12 protein to split the single-stranded DNA probe abundantly with the fluorophore group and the terminal-labeled quencher, thereby turning on fluorescence[14].

Applications of Proteomics Methods to Identify Unique Proteins from Foods

Proteomics is a complex field of study consisting of structural proteomics, which investigates the 3D structure of proteins[15]. Most proteomic discoveries and efforts have been primarily directed at cancer research, target drug and drug discovery, and biomarker research[16]. In terms of biomarkers, we can use this to detect bioactive peptides in foodstuffs. This further strengthens the proteomic approach as a method of screening, validating, and standardizing food matrices. Furthermore, deficiencies in the ability of bioinformatics to predict the presence and function of genes have also illustrated the need for protein analysis. Moreover, it can only be determined through the study of post-translational modification of proteins, which can significantly affect the functioning of proteins[17]. This approach's potential accuracy certainly needs further utilized in food authentication, primarily through bioactive peptide biomarkers. Each food has its unique bioactive peptide. One research tried to innovate by creating a database dedicated to collecting all bioactive peptides with known structures[18]. Proteomics based on multiple reactions-monitoring (MRM) has been used to confirm the presence and measure the bioactive proteins αs1-casein, α-lactalbumin, and β-lactoglobulin in different food products. In this article, we attempt to push why proteomics is essential, how it is done, and how it can be applied to complement food authentication technologies. We conclude that proteomic application is currently the most practical in analyzing target proteins compared to the entire proteome. However, this technology has a limit since it must be carried out using expensive and complicated laboratory equipment. A more applicable and affordable, portable sequencing protein will be preferred (Table 1).

Metabolomics Profiling Untargeted to Collect Typical Metabolites from Foods

Metabolomics is a large-scale study of small molecules, commonly known as metabolites, inside cells, biofluids, tissues, or organisms[19]. These small molecules and their interactions in biological systems are collectively known as metabolomics[20]. A compelling approach to conduct this metabolomics identification is liquid chromatography coupled with high-resolution mass spectrometry (HPLC-ESI-HRMS/MS), which is increasingly used in metabolomics, allowing comprehensive analysis of phytochemicals and semiautomatic collection of study samples[21]. There has been ample evidence that LC-HRMS is an unsettled method for food authentication by looking at the marker of secondary metabolites that are unique or unique to each type of food ingredient. A study mentioned new strategies for validating and retrieving fresh and frozen/thawed fish, especially the EPA and DHA markers representing it[22]. Furthermore, HRMS can be an alternative to rapid authentication of milk from Alpine or lowland forage based on energetic marker compounds, amines, ketoacid derivates, and organic acids[23]. This makes LC-HRMS or untargeted profiling metabolomic approaches promising solutions to be used to screen, validate, and standardize food matrices. Metabolomics is a powerful approach because its metabolites and concentrations, unlike other "omics" measures, directly reflect the underlying biochemical activity and state of the cell or tissue. Therefore, metabolomics is most representative of the molecular phenotype. Recently we highlighted the advanced research of technology[24]. They invented an advanced technology of electrochemical biosensors that can be used to monitor metabolites and nutrients in the form of watches. They present a universal wearable biosensing strategy based on combining or integrating mass-producible laser-engraved graphene (LEG), electrochemically synthesized redox-active nanoreporters, and molecularly minted polymer-based artificial proteins (MIP), as well as unique *in situ* regeneration and calibration technologies. It would be interesting and useful if this technology could be applied and commercialized as food authentication through validating metabolites.

DISCUSSION

Foodomics consists of four main technologies omics, namely genomics, transcriptomics, proteomics, and metabolomics. It is an integration of promising approaches in providing standardized food matrices so that it becomes a possible strategy to verify food authenticity (Figure 1 and Table 1).

The ingredient can be carried out and identified through genomics genome mapping of each food. The uniqueness of the food genome is expected to be a marker in verifying food authentication, and the results can become standardized food matrices (Figure 1). It can identify the regional origin of an organism or food by matching databases, such as gene banks, and of course, seeing whether foodstuffs have been genetically modified. In addition, the next omics approach that also has the potential to facilitate verification of the authenticity of foods is transcriptomics. Transcriptomics is a collection of RNA molecules derived from protein-encoding genes expressed in biology (Figure 1). These protein or RNA coding genes can be a marker or food matrices (in the form of unique genes) to verify food authenticity (Figure 1). Furthermore, proteomics also seems applicable to verifying food authenticity (Figure 1). The potential accuracy of this proteomic approach certainly needs to be further utilized in food authentication, especially through bioactive peptide biomarkers. Furthermore, metabolomics – especially untargeted metabolomic profiling – is intriguing since it can detect compounds or secondary metabolites typical of each food ingredient (Figure 1). The integration of these four technologies referred to as the foodomics approach needs to be implemented. The approach of the new research mentioned in Table 1 was based on a collection of data obtained using a cost-effective and easy-to-handle technique (Table 1)[26]. Furthermore, using chromatography, ambient mass spectrometry (AMS) method was also developed which was capable of screening 40 poisons and successfully performing an initial screening of suspected poison baits that can guide the choice of confirmation methods reference[27], reducing the burden on official laboratories, and assisting in the early stages of investigations of animal poisoning cases and possibly other animal foodstuffs.

Electrochemical DNA biosensors offer an exciting alternative and potential to traditional and conventional detection methods due to their low price, simple product process, and ease to carry[8], compared to single nucleotide polymorphisms (SNPs) as food authenticity detector candidates (Figure and Table 1). A new approach was devised to read the results of detecting *E. coli* O157:H7 in yogurt and eggs with a smartphone based on a field portable fluorescent imager, which showed low noise in the background imaging system[28]. Similarly, a study proposed a bioassay based on dual-wavelength fluorescence integrated with smartphones to detect biomolecules, which have high accuracy and can obtain clear results[29]. In the future, developing mini and portable biosensors can be a research direction. In addition, the incorporation or integration of foodomics-electronics (genomics-transcriptomics-proteomics-metabolomics-metallomics-volatomics-lipidomics and electronics) can be an alternative in food authenticity, such as the research results which found that metal-enhanced fluorescence (MEF) can reduce false negative signals with lower detection limits on label-free and dual-wavelengths biosensor innovations based on smartphone imaging[29]. The new method has great potential as an accurate point-of-care testing technology based on a mobile platform for clinical diagnostics and environmental monitoring.

CONCLUSION

However, after trying to uncover this food authentication problem and providing a foodomics approach, we feel the need for synergy in building a database capable of storing food matrices in the form of unique genes, bioactive peptides, and secondary metabolites. We hope that, through this opinion article, its intended database can be established although databases such as MEDLINE and PubChem have already provided this data facility. However, using an accessible and unique database to detect the originality of foodstuffs needs to be considered. Based on the presentation of opinions and literature above, several research suggestions were highlighted. Specifically, we suggest the development of nanobiosensors that must undoubtedly be environmentally friendly and portable (utilizing smartphones) and creating a cloud database capable of storing food matrices in the form of unique genes, bioactive peptides, and secondary metabolites, which are integrated with smartphone biosensors. Moreover, the modification and development of the findings of Minqiang Wang (Table 1) in its application to verify the authenticity of foods will also be beneficial. Of course, we realize that this is an opinion article, which is not only based on appropriate data and references but future research that refers to this can be done, with hopes that startups in the technology field can develop it. Finally, as a result, the researchers try to answer this database problem so that foodomics integrated with the database can solve the problems of detecting fraud and falsifying foodstuffs or foods.

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