# 学 位 論 文 内 容 の 要 旨

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## 学 位 論 文 題 名

Application of foodomics towards identification and characterization of bioactive lipids in dietary grains and herbs
(食用穀物およびハーブに含まれる生理活性脂質の同定と特性解析に向けたフードミクスの応用)


### Abstract

Lipids are fundamental components of food that serve not only as a source of energy but also as essential molecules involved in cellular structure, signaling, and regulation of metabolic processes. In recent years, the nutritional importance of specific lipid classes, such as polyunsaturated fatty acids (PUFAs), sterol lipids (STs), and bioactive lipid derivatives, has gained increasing attention for their roles in promoting health and preventing lifestyle-related diseases, including obesity, diabetes, and cardiovascular disorders. Despite this growing interest, much of the existing lipidomic research has focused on animal and clinical systems, while the diversity and function of plant-derived lipids, particularly those found in traditional herbs and whole grains, remain underexplored. This study addresses the gap by applying untargeted lipidomics to identify and characterize novel lipid species in Japanese herbs, sorghum, and rice cultivars. It asks how lipid profiles vary across plant types, what new bioactive lipids can be uncovered, and how these relate to nutritional function and potential agricultural applications. Using high-resolution liquid chromatography-mass-spectrometry, the study identified hundreds of lipid molecules and discovered several novel species such as fatty acid esters of hydroxy fatty acids (FAHFAs) and N-acyl-lysophosphatidylethanolamines (LNAPEs). Functional assays, including glycemic index prediction, confocal imaging, and gene expression studies, linked lipid profiles to health-related traits and plant physiological responses. The findings highlight the value of lipidomics in food science, uncovering unique plant lipids with potential nutritional and agronomic significance.

Chapter one presents an overview of dietary lipids, their classifications, occurrence in food, and the emerging role of foodomics in a comprehensive analysis of lipids. The chapter addresses the limitations in current lipidomics methodologies, particularly the lack of standardized protocols for food lipid analysis. It highlights future trends integrating lipidomics with other omics technologies for precision nutrition.

In Chapter two, a non-targeted lipidomic study was performed on four traditional Japanese herbal teas. Using high-resolution LC-Orbitrap-MS analysis, a total of 344 lipid molecular species

were identified across various lipid classes, including fatty acyls (FAs), glycerophospholipids (GPs), glycerolipids (GLs), sphingolipids (SPs), and STs. Importantly, four novel short-chain fatty acid esters of hydroxy fatty acids (SFAHFAs) were discovered for the first time in these herbal teas. Multivariate statistical analysis revealed distinct lipidomic profiles between tea species, demonstrating both compositional diversity and potential health-promoting lipid content in herbal beverages.

Chapter three extends lipidomic profiling to six commercial sorghum cultivars grown under controlled field conditions in Australia. A total of 194 lipid molecular species were annotated, highlighting significant differences among cultivars in total lipid content and fatty acid composition. Cultivars such as MR43 and Bazley displayed higher levels of PUFAs and FAHFAs, offering promising dietary and health benefits. The study also identified five novel FAHFAs in sorghum grain for the first time. It also utilized derivatization techniques to confirm hydroxyl positions in these molecules. This chapter establishes the unique lipidomic signatures of sorghum cultivars, emphasizing their nutritional potential and functional application in health-oriented grain products.

Chapter four presents an integrated analysis of lipidomics and glycemic response in 56 pigmented *japonica* rice cultivars. A total of 198 lipid species across five categories were profiled, leading to the identification of novel bioactive lipids, including FAHFAs and LNAPEs. Among the selected cultivars, black and green rice varieties exhibited healthier lipid profiles, with higher polyunsaturated to saturated fatty acid ratios, increased health promotion indices, and lower estimated glycemic index (eGI) values. Multivariate analysis further revealed that fatty acyls and glycerophospholipids were key markers distinguishing farming practices. These findings offer valuable molecular insights into the nutritional quality of pigmented rice and support the development of low-eGI rice cultivars for better metabolic health.

Chapter five explored the agricultural application of hijiki-derived carbon nanodots (CND-H) on rice seedling growth. The study confirmed the successful uptake of CND-H in germinating rice grains using confocal microscopy and emission spectral matching. Seed germination studies demonstrated enhanced shoot and root elongation in CND-H-treated seedlings compared to controls. Furthermore, gene expression analysis revealed a significant upregulation of *OsDGAT1*, a key enzyme in triacylglycerol biosynthesis, indicating a possible lipid accumulation-promoting effect of CND-H treatment in rice seedlings. While no significant change was observed in *OsACBP4* expression, these preliminary results suggest a beneficial role of nanomaterials in promoting seed vigor and lipid metabolism.

Overall, this thesis advances the understanding of plant lipid diversity, reports several novel lipid molecular species for the first time, and demonstrates the potential of lipidomics combined with functional studies in both nutritional science and agriculture. The findings emphasize the importance of untargeted lipidomics in identifying health-relevant lipids in food crops and herbal products and propose innovative strategies, including nanotechnology, for improving crop performance and lipid quality.