Rice Landrace Varieties and Fatty Acid Diversity: Profiling of Fatty Acid Variability of Parboiled and Un-parboiled Abakaliki Rice Landraces in Nigeria

Anyairo Chioma Stella[1,4,*], Obaji Ndubuisi Raymond[2], Elechi Jasper Okoro Godwin[3], Ogah Onwuchekwa[4]

[1]Division of Biotechnology, Faculty of Agro-Industry, The Graduate School, Chiang Mai University, 50100, Chiang Mai, Thailand; https://orcid.org/0000-0002-8202-0472
[2]Laboratory of Structural and Biological Chemistry Graduate school of life science Faculty of Advanced Life Science, Hokkaido University, Japan; https://orcid.org/0000-0003-4128-3134
[3]Department of Pharmacy, Health and Nutritional Sciences, University of Calabria, 87036 Rende, CS, Italy; https://orcid.org/0000-0001-5623-4189
[4]Biotechnology Department, Ebonyi State University, Abakaliki, Nigeria; (OO).

*Corresponding Author: chianyairo@gmail.com; *ORCID iD *https://orcid.org/0000-0002-8202-0472*

Abstract
Rice (Oryza sativa) is among Nigeria's top priority staple crops that play a role in food security and livelihood resilience within the household. Different varieties of rice landraces are grown in Nigeria; Abakaliki rice is grown in Ebonyi State and consumed in almost all parts of the country. This study evaluated the fatty acid composition of parboiled and un-parboiled Abakaliki rice landraces. The GC-MS analysis revealed that myristic, myristoleic, oleic, linoleic and vaccenic fatty acids were the most dominant in the rice landraces. In addition, all study samples contain a total amount of vaccenic (34.45%), oleic (33.36%) and myristic (21.68%) fatty acid, however myristoleic (3.3%) and linoleic (7.5%) fatty acid is in low amount. This study reveals that these fatty acids are 63.82% higher in the parboiled rice cultivars than in the un-parboiled rice.

Keywords: Abakaliki, parboiled rice, vaccenic acid, Fatty acids, Landrace, Nigeria

1.0 Introduction

Rice(Oryza sativa L.), one of the most significant grains in the world(Oryza sativa L.) is the second-most important crop after wheat and is a staple diet for more than 3 billion people (Zhang *et al.*, 2022; Abbas *et al.*, 2011). With a worldwide production of 645 million tons, rice is cultivated in at least 114 nations (IRRI, 2008). Only five countries (Nigeria, the Democratic Republic of the Congo, and Ethiopia in sub-Saharan Africa, India, and Bangladesh in South Asia) on two continents house half of the world's poorest citizens (Roy and Divyanshi, 2021). In three of these nations, rice consumption is high on the list of staple foods. India (103 kg/capita and 104 megatons), Bangladesh (260 kg/capita and 36.1 megatons), Nigeria (46.3 kg/capita, 6.60 megatons), the Democratic Republic of the Congo (29.7 kg/capita, 0.47 megatons) (Roy and Divyanshi, 2021; Index Mundi, 2021; Uyeh *et al.*, 2021). Two of these nations—Nigeria, which spends $8.5 billion on 1.8 megatons, and Bangladesh, which pays $4.03 billion on 0.9 megatons—are among the top 10 rice importers in the world (FAOSTAT, 2020). These nations have high food insecurity and malnutrition (World Bank, 2021). Unlike in the past, rice is now a staple of Nigerians' meals due to population increase, consumer desire, the opportunity cost of their time, and the convenience of cooking it. Today, rice is readily available on the streets of cities and villages, unlike in the past when Nigerians only ate rice during rituals or holidays like *Christmas*, *Easter*, *Idel-filtri*, and *Idel-Kabir* (Olumuyiwa, 2014). As a result, Nigeria, the second-most populated nation in Africa, was listed as the world's second-largest rice importer (Cadoni and Angelucci, 2019), and rice ranked fourth in calorie intake. Despite being the largest producer of rice in West Africa, Nigeria, productivity is often low (Uyeh *et al.*, 2021).

Physical characteristics such as head rice yield, chalkiness, grain size and shape, colour, stickiness, protein and amylose content, and flavour are the main factors used to evaluate rice quality (Yanjie *et al.*, 2018; Odenigbo *et al.*, 2014). These qualities of rice impact its physicochemical makeup and cooking abilities, which affect customers' preferences (Uyeh *et al.*, 2021). In addition to vitamins, minerals, carbohydrates, and a little protein, studies have shown rice to include several fatty acids (FAs) as a lipid component (Rathna *et al.*, 2019). Along with food availability and entitlement, the understanding of nutritional richness's role in food security is expanding (Ray *et al.*, 2021).
According to recent studies, a lot of forgotten rice landraces contain significant levels of B-complex vitamins, metallic micronutrients and other antioxidant compounds (phenols and flavonoids) that are not present in any current high-yield varieties (Roy *et al.*, 2020; Deb *et al.*, 2017; Mondal *et al.*, 2021). Alpha-linolenic acid (18:3 ω3; ALA) and linoleic acid (18:2 ω6; LA), which are sourced from plants or marine creatures, are the sole dietary components that are utilised in the de novo synthesis of Long-chain polyunsaturated fatty acids (LCPUFAs) in the human body since humans lack the substrate-specific desaturase enzymes (Ballantyne, 2014). The only plant-based ω3 Fatty acid that slows the development of lysophosphatidic acid, a factor in the advancement of neuropathic and inflammatory pain (Alexa-Stratulat, 2017), is ALA (18:3 ω3) (Woolf and Salter, 2000; Ray et al., 2021). Eicosapentaenoic acid (20:5 ω3; EPA) and docosahexaenoic acid (22:6 ω3; DHA) are two other ω3 FAs that are conditionally essential. EPA is a significant factor in platelet aggregation and precursor to prostaglandin (Woolf and Salter, 2000; Ray *et al.*, 2021). At the same time, ω6 Fatty acids and DHA are essential for the phospholipid component of the cell membrane's architecture. They are in charge of preserving membrane permeability, promoting macromolecular movement, and stimulating bioactive lipid mediators' production (Rosedale, 2017). These polyunsaturated fatty acids (PUFAs) have a significant impact on signal transduction pathways, lower reactive oxygen species (ROS), and are precursors of several secondary metabolites (EFSA, 2012). Dietitians and nutritionists advise brown rice to be best (Kaur *et al*. 2020). As it lowers asthma because of antioxidants and phytonutrients, helps prevent cancer (Tian *et al.*, 2004), boosts energy (fibre), promotes healthy bone development, and avoids gallstones and atherosclerosis (Kaur *et al.*, 2020).
Rice is a widespread staple meal; however, the rice products consumed vary greatly depending on type, processing technology (cleaning rice by removing the husk and bran), and pre-cooking treatment (e.g. parboiling) (Lu *et al.*, 2018). Parboiling can improve the physicochemical characteristics of rice starch. Thereby eliminating the usage of additives like texturising proteins, gums, and emulsifiers in rice processing (Caiming *et al.*, 2021). Parboiling is a hydrothermal treatment of coarse rice grains that consists of three significant steps: soaking, steaming and drying (Rocha-Villarreal *et al.*, 2018). Parboiled rice is paddy rice with a yellowish tint, firm and chewy texture, and a robust flavour.

On the other hand, white rice has a pale white hue, a soft and sticky texture, and a mild and starchy flavour (Dutta and Mahanta, 2012). For parboiled brown rice processing, the paddy is soaked, heat treated, and dried before being husked and milled to the required degree of whiteness (Oli *et al.*, 2014, Taleon *et al.*, 2020). Indeed, parboiling is said to affect the structural features of rice starch, transforming it from crystalline to amorphous, resulting in a very compact and transparent endosperm and increasing the sensory, cooking, and texture aspects of rice grains (Taddei *et al.*, 2021; Marti *et al.*, 2013). Parboiling causes the formation of lipid-amylose complexes and the aggregation of soluble proteins, resulting in less starch swelling and amylose leaching during cooking, less stickiness, and more hardness (Taddei *et al.*, 2021; Bhattacharya, 2004). The nutritional qualities of rice improve with parboiling due to the migration of vitamins and minerals towards the endosperm, as well as an increase in resistant starch (RS) content (Zohoun *et al.*, 2018), which appears to offer considerable benefits to the human colon health (Nugent *et al.*, 2005). Parboiling rice can increase its oxidative stability and extend its storage life (Koh and Surh, 2016; Zhang *et al.*, 2022). In addition, by adding minerals and vitamins to the soaking water, parboiling can enrich rice with minerals and vitamins (Patindol *et al.*, 2017; Jannasch & Wang, 2020).

The most significant barrier to rice farming in Africa is inconsistency in water supply, as irregular and low rainfall patterns leave crops prone to drought (Uyeh *et al.*, 2021). As one of Nigeria's most significant crops, its production is critical to the government's effort to combat food shortages and enhance self-sufficiency for domestic consumption and export (Olumuyiwa, 2014). Therefore, there is a need for the government to promote indigenous foods by adopting transparency in food systems and innovation in food manufacturing technologies and packaging. This increases the product's shelf life and meets consumers' needs, thereby assuring food safety and security (Elechi *et al.*, 2022). Integrating staple foods, increasing staple food health qualities, and reducing obstacles to eating healthier foods all contribute to better nutrition and food security (Dixon *et al.*, 2020). The two rice species commonly cultivated globally are (African *Oryza glaberrima* and Asian *Oryza sativa*) (Linares, 2002). They are physically similar but ecologically distinct. Compared to the Asian O. sativa, *O. glaberrima* is more resistant to illnesses and pests (Linares, 2002). Furthermore, *O. glaberrima* is less prone to weeds due to its broader leaves, which shade weeds. Furthermore, the African species are more resistant to changes in water depth, harsh temperature, iron poisoning, and barren soil. Because of its rapid maturation rate, *O. glaberrima* has significant potential as an essential emergency food (IRR1, 2008). However, the larger yields of Asian *O. sativa* outperform *O. glaberrima*, whose grains are brittle and difficult to process. Hybrids of the two primary varieties have been created to keep their favourable characteristics. *O. glaberrima* is mainly grown in Sub-Saharan Africa; however, it is being supplanted by *O. sativa.* As a result, several rice landraces in Nigeria fulfil the local population's food security and nutritional demands.

Parboiled rice is typical over milled rice in many African, Asian, and European nations. In recent years, producers and food experts have become increasingly interested in the changeable digestibility of parboiled rice. Abakiliki rice is one of Nigeria's most famous rice landraces. However, despite Nigerian landraces' unique fatty acid variety, little attention has been dedicated to rice landrace variations thus far. As a result, this study aimed to assess the type of fatty acid characteristics in Nigerian Abakiliki rice landrace variants as affected by parboiling. This research addresses the rising demand for healthier foods while also promoting the growth of the local rice sector.

2.0 Materials and Methods

2.1 Sample collection

A total of 16 Abakaliki rice landraces from seven different locations within Ebonyi State, Nigeria, were collected from native farmers to ensure all samples' pureness during July - December 2019 crop harvest cycle based on the various varieties harvesting season. These rice cultivars have different local names, as shown in Table 1. The sample collection areas were Ezzamgbo, Abaomege, Izzi, Ikwo, Onueke, Abakaliki and Ezza.

Table1 : **Samples local names and locations**.

Locations	Samples Local names
Ezza	Nwangbasianya, 306
Ikwo	Nwadaugo, CP, Mirimiri, Farro44, Atom, China, Mass, Ogologombada
Ezzamgbo	Farro
Abaomege	Akuje, Kpurukpuru
Izzi	Farro 44
Onueke	Iron2
Abakaliki	R8

2.2 Sample preparation

About 20g of paddy rice was manually dehusked by hand for the un-parboiled rice samples. For the parboiled Abakaliki rice samples, 500g of the paddy rice was parboiled using a local pot and gas cooker. The paddy rice was put in the local pot containing 500ml of water, placed on the gas cooker, and heated to 70ºC. After heating, the samples were left in the water overnight, after which the samples were then pre-parboiled with 50ml of clean, fresh water and then sundried for 40mins. The sundried rice was manually milled.

2.3 Paddy soaking and steaming

A traditional double-boiled process method was used; the paddy is soaked in water at room temperature and steamed for a short period, after which the samples are left in the water overnight before draining and steaming with clean, fresh water for the second time and then sundried. For each rice landraces, 1000 g of paddy were soaked in 1600 mL of tap water at room temperature for four hours to reach a moisture content of 33 ± 2%. For steaming, the paddy rice soaked in the local pots was placed in the gas cooker and heated to 70ºC for 15 minutes. After heating, the samples were left in the water overnight, after which the samples were drained and then parboiled with 200ml of clean tap water until the husk of most paddy grains became slightly open. This reveals that the grain was sufficiently steamed to prevent excessive under-parboiled and over-parboiled kernels (Taleon *et al.*, 2020). After boiling, the parboiled paddy was cooled down immediately and sprayed on a clean plastic surface. Steamed paddy was sun-dried to 11.0–13.0% moisture content.

2.4 Milling

Parboiled rice was obtained by de-hulling the dried, steamed rice with the Rice huller (JLGJ 4.5, Taizhou, China). The parboiled rice was grounded to flour, which passed through a 100-mesh screen. The flour was used for the analysis of fatty acids.

2.5 Analysis of fatty acid methyl ester

The total lipid was extracted from pulverised decorticated rice following the modified method of Bligh and Dyer (1959 as cited by Ray et al., 2021), modified by Poddar (1996). FAs were trans-esterified into fatty acid methyl ester (FAME) using methanol/benzene/concentrated H_2SO_4 (in the proportion of 4.3:0.5:0.6 by vol). And then kept at 85^{0}C for 8 h, after which it was extracted with n-hexane (HPLC grade, E. Merck, India) and then subjected to GCMS (Agilent Technologies, USA, 7890A GC system with 5975C triple axis detector MS attached with HP5-MS (30 m x 0.25 mm x 0.25 µm) + 10 m Duraguard capillary column). GC-MS analysis of the samples was performed using HP Capillary; 60m x 0.25mm, 0.25um. The setup used was adopted from a study by Kan (2015). The column temperature was held initially at 60ºC for 3mins after the injection, then increased to 185ºC with 10ºC min^{-1} heating ramp, and increased to 200ºC with 5ºC min^{-1} heating ramp for 10min. Then, the final temperature was 220ºC with a 5ºC min^{-1} heating ramp for 20 mins. The injector temperature was 250ºC; the detector (FID) temperature was 275ºC. The carrier gas was He with an inlet pressure of 40.65psi. The linear gas velocity was at 39cm S-1 where the column flow rate was 2.7mL min^{-1}. The splitless mode was used with an injection volume of 1Ul. Agilent 6890N system was used for the GC/MS analysis combined with Agilent 5973 MS Selective Detector. The GC condition were; as column HP innowax capillary (60m X 0.25mm, 0.25µm). The oven temperature program was set so that the column was held initially at 60ºC for about 3min after injection, then increased to 185ºC with 100ºC min^{-1} heating ramp and increased to 200ºC with 5ºC min^{-1} heating ramp for 10 mins. Then the final temperature was increased to 220ºC with a 5ºC min^{-1} heating ramp for 20 mins. The injector temperature was set to 250ºC. The carrier gas was helium with an inlet pressure of 40.65 psi. The linear gas velocity was 44 cm s^{-1} at a column flow of 2.9 ML min^{-1} in splitless mode. The MS condition was; ionisation energy was 70 eV, the ion source temperature was 280ºC, the interface temperature was 250ºC and the MS range was set 35-450 atomic mass units.

2.6 Statistical analysis

All analytical determinations were conducted in 3 replications. Means and standard deviations were calculated. Data obtained were subjected to analysis of variance (ANOVA). Duncan's new multiple range tests (DNMRT) were used to compare the treatment means. Statistical significance was accepted at ($p>0.05$).

3.0 Results and Discussion

3.1 The Fatty Acid Profile Un-parboiled Abakaliki Rice Landraces

The results showed that the most common fatty acids dominant in all the samples were; Myristics, myristoleic, oleic, vaccenic and linoleic acids as shown in Table 2. However, this is one of the very few studies to report the presence of vaccenic acid in rice. The range of Myristic acids in un-parboiled rice was 0.0-2.177%. The myristic was 0% in U-FARRO (Ezzamgbo) and highest (2.177%) in U-Farro44

(Ikwo) and U-Atom (Ikwo) respectively. Myristoleic acid ranged from 0.00 - 0.427% with U-Kpurukpuru (Abaomege) and U-Atom (Ikwo) recording the lowest and highest values respectively. The range of Oleic acids in un-parboiled rice was 0.327-5.02%. The Oleic was 0.327% in U-306 (Ezza) and highest (5.02%) in U-FARRO (Ezzamgbo) respectively. Vaccenic acid ranged from **0.207** - 4.50% with U-Ogologomgbada (Ikwo) and U-FARRO (Ezzamgbo) recording the lowest and highest values respectively. Linoleic acid was in the range of 0.0% (U-Ogologomgbada -Ikwo; U-Farro44 – Ikwo; U-306 -Ezza) to 2.317% (U-Kpurukpuru -Abaomege)

Table 2: Fatty acid Composition of the Abakaliki Un-parboiled Rice Samples (%)

Rice Landraces	Location	Myristic	Myristoleic	Oleic	Vaccenic	Linoleic
U-Nwangbasianya	Izza	1.497±0.06^{d}	0.357±0.08^{abc}	1.873±0.35^{de}	2.67±0.5^{bcd}	0.187±0.22^{a}
U-Nwadaugo	Ikwo	0.52±0.5^{ab}	0.187±0.22^{abc}	1.15±0.50^{bc}	0.59±0.5^{a}	0.147±0.19^{a}
U-FARRO	Ezzamgbo	0.0±0E-7^{a}	0.227±0.08^{abc}	5.02±0.50^{h}	**4.50±0.5^{g}**	0.22±0.10^{a}
U-CP	Ikwo	1.1±0.5^{cd}	0.063±0.03^{ab}	2.357±0.40^{efg}	3.153±0.45^{de}	0.147±0.09^{a}
U-Akuje	Abaomege	0.447±0.15^{ab}	0.020±0.01^{a}	0.71±0.15^{ab}	0.367±0.15^{a}	0.02±0.01^{a}
U-Farro44	Izzi	0.417±0.25^{ab}	0.047±0.02^{ab}	0.667±0.32^{ab}	0.417±0.15^{a}	0.043±0.03^{a}
U-Mirimiri	Ikwo	0.39±0.30^{a}	0.05±0.01^{ab}	0.637±0.15^{ab}	0.463±0.21^{a}	0.173±0.27^{a}
U-Ogologomgbada	Ikwo	0.26±0.10^{a}	0.04±0.04^{a}	0.417±0.15^{a}	**0.207±0.15^{a}**	**0.0±0E-7^{a}**
U-Iron	Onueke	2.037±0.32^{e}	0.103±0.09^{ab}	2.03±0.36^{def}	3.02±0.27^{cde}	0.127±0.09^{a}
U-R8	Abakaliki	1.223±0.21^{cd}	0.197±0.20^{abc}	2.487±0.32^{fg}	3.327±0.32^{ef}	0.187±0.23^{a}
U-Farro44	Ikwo	2.177±0.32^{e}	0.177±0.26^{abc}	0.610±0.29^{ab}	0.33±0.27^{a}	**0±0E-7^{a}**
U-Atom	Ikwo	2.177±0.32^{e}	0.427±0.29^{bc}	2.910±0.32^{g}	3.807±0.32^{f}	0.197±0.19^{a}
U-China	Ikwo	0.907±0.32^{bc}	0.193±0.21^{abc}	1.587±0.32^{cd}	2.487±0.32^{bc}	0.183±0.24^{a}
U-Mass	Ikwo	1.11±0.06^{cd}	0.187±0.23^{abc}	1.147±0.29^{bc}	0.697±0.29^{a}	0.177±0.26^{a}
U-306	Ezza	0.283±0.11^{a}	0.173±0.27^{abc}	0.327±0.26^{a}	0.267±0.05^{a}	**0±0E-7^{a}**
U-Kpurukpuru	Abaomege	0.237±0.29^{a}	0.0±0.00	0.797±0.29^{ab}	1.197±0.29^{b}	**2.317±0.29^{b}**

Values on the same column with different superscripts are significantly different (P<0.05)

3.1 The Fatty Acid Profile parboiled Abakaliki Rice Landraces

Table 3 depicts the result of the fatty acid profile of parboiled rice. There was a significant increase in Myristic acid for P-FARRO, Ezzamgbo (3.397%); P-Akuje, Abaomege (1.767%); P-Farro44, Izzi (1.177%); P-Ogologomgbada Ikwo (1.757%); P-R8, Abakaliki (2.517%); P-Mass, Ikwo (3.067%); P-306, Ezza (2.427%); P-Kpurukpuru, Abaomege (2.237%); while P-Farro44, Ikwo (1.177%); P-Atom, Ikwo (0.597%); P-China, Ikwo (0.33%). This trend was similar in Myristoleic, Oleic, Vaccenic, and Linoleic across the rice landraces. Other studies have shown a decrease and increase in fatty acid parboiled rice (Achidi *et al.*, 2021; Adekoyeni, 2014; Danbaba *et al.*, 2014; Parnsakhorn & Noomhorm 2008; Kimura et al., 1993). However, this present study demonstrated that the increase or decrease in fatty acid content in rice is dependent on the geographical location, soil type, other climatic conditions and genetic makeup of the cultivars and the various unit operation the processing treatment undergoes (Shen *et al.*, 2009; Kumar *et al.*, 2022).

Except for linoleic acid, the body requires fatty acids, which it can obtain from dietary carbohydrates, proteins, and lipids. Linoleic acid accounts for over 30% of rice's total fatty acid content. According to Bryant et al. (2011), aromatic and non-aromatic rice types contain various unsaturated fatty acids, which have antifungal properties and accumulate with ageing. According to (Olumuyiwa, 2014), increasing the soaking duration and parboiling temperature resulted in a drop in free fatty acids while increasing the drying temperature also decreased the fatty acid content of ofada rice. Lipase, an enzyme that speeds up the fat reaction, is impacted or inactive by high temperatures (Ruskin, 1996). The different processing methods might cause misdirected reactions that result in the formation of free fatty acids. The findings demonstrated that certain processing conditions might remove unsaturated fatty acids in rice during processing.

Table 3: Fatty acid composition of the Abakaliki parboiled rice samples (%)

Rice Landraces	Location	Myristic	Myristoleic	Oleic	Vaccenic	Linoleic
P-Nwangbasianya	Izza	0.677±0.29^{abcd}	0.19±0.22^{a}	1.137±0.29^{bc}	0.577±0.29^{ab}	0.177±0.26^{a}
P-Nwadaugo	Ikwo	0.837±0.29^{bcd}	0.193±0.21^{a}	1.257±0.29^{bcd}	0.927±0.29^{bc}	0.173±0.29^{a}
P-FARRO	Ezzamgbo	3.397±0.29^{i}	0.22±0.11^{a}	6.337±0.29^{i}	5.047±0.29	0.207±0.17^{a}
P-CP	Ikwo	1.067±0.29^{cd}	0.297±0.15^{b}	1.597±0.29^{cde}	2.387±0.29^{d}	0.18±0.25^{a}
P-Akuje	Abaomege	1.767±0.29^{e}	0.203±0.17^{a}	1.647±0.29^{cde}	2.547±0.29^{d}	0.187±0.23^{a}
P-Farro44	Izzi	1.177±0.29^{d}	0.203±0.19^{a}	1.777±0.29^{de}	1.187±0.29^{c}	0.183±0.24^{a}
P-Mirimiri	Ikwo	0.527±0.29^{ab}	0.187±0.23^{a}	0.517±0.29^{a}	0.427±0.29^{ab}	0.173±0.27^{a}
P-Ogologomgbada	Ikwo	1.757±0.29^{e}	0.20±0.18^{a}	1.857±0.29^{e}	2.527±0.29^{d}	0.187±0.23^{a}
P-Iron	Onueke	2.947±0.29^{hi}	0.237±0.06^{a}	3.527±0.29^{g}	4.067±0.29^{f}	0.197±0.19^{a}
P-R8	Abakaliki	2.517±0.29^{fgh}	0.223±0.10^{a}	3.577±0.29^{g}	3.977±0.29^{f}	0.20±0.18^{a}
P-Farro44	Ikwo	1.177±0.29^{d}	0.203±0.19^{a}	4.747±0.29^{h}	4.787±0.29^{g}	0.21±0.15^{a}
P-Atom	Ikwo	0.597±0.29^{abc}	0.187±0.23^{a}	0.787±0.29^{ab}	0.547±0.29^{ab}	0.173±0.27^{a}
P-China	Ikwo	0.33±0.27^{ab}	0.18±0.25^{a}	0.487±0.29^{a}	0.317±0.29^{a}	0.0±0E-7^{a}
P-306	Ezza	2.427±0.29^{fg}	0.227±0.09^{a}	3.297±0.29^{g}	3.817±0.29^{f}	0.193±0.21^{a}
P-Mass	Ikwo	3.067±0.29^{i}	0.247±0.02^{a}	4.797±0.29^{h}	5.417±0.29^{h}	0.21±0.15^{a}
P-Kpurukpuru	Abaomege	2.237±0.29^{ef}	0.20±0.18^{a}	2.797±0.29^{f}	3.197±0.29^{e}	7.317±0.29^{b}

Value on the same column with different superscripts are significantly different (P<0.05)

Percentage Comparison, Correlation Analysis and Principal Component Analysis (PCA) of the Fatty Acid Content of Parboiled and Un-Parboiled Abakaliki Rice Landrace

The overall concentration of all fatty acids is higher in parboiled rice samples than in the un-parboiled rice samples in this investigation (Figure 1). This could be linked to the oil globules being leached and ruptured due to increased temperature and steaming pressure during the parboiling process (Chukwu and Oseh, 2009). From the PCA and correlation analysis (Figures 2 and 3), it can be deduced that our study components are strongly correlated to the vaccenic fatty acid except for myristoleic and myristic, which are independent of the vaccenic acid. Therefore, it is beyond the scope of this study to determine this relationship.

The nutritional value of FA in health concerns was historically clarified by classifying it according to different degrees of unsaturation, i.e. the amount and combination of double bonds, relative ratios of S.F.A.s, MUFAs, and PUFAs, and so on. According to Gutieerez (2002), the primary dietary component contributing to high cholesterol levels, which can contribute to excess body weight gain, is the consumption of high levels of saturated fat. Kromhout et al. (1995) observed that consuming myristic acid raises blood cholesterol levels, contributing to coronary artery disease. However, compared to myristic fatty acid, the only saturated fatty acid in these samples, this research sample's dietary fatty acid compositions include a more significant percentage of unsaturated fatty acids. As a result, it is insignificant compared to the saturated fatty acids found in parboiled and un-parboiled Abakaliki rice.

Figure 1: Percentage Comparison of the fatty acid content of Abakaliki parboiled and un-parboiled.

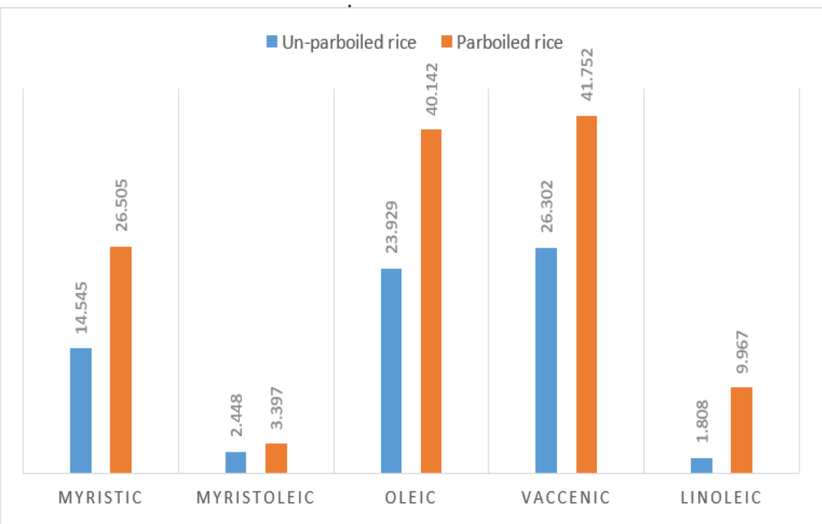


Figure 2: correlation analysis

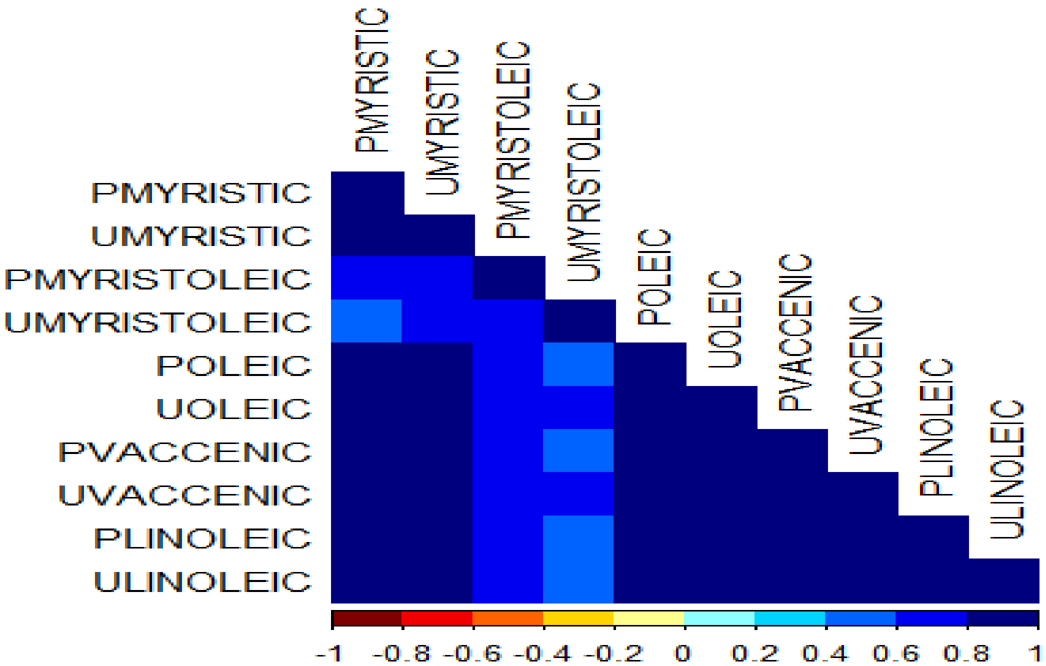
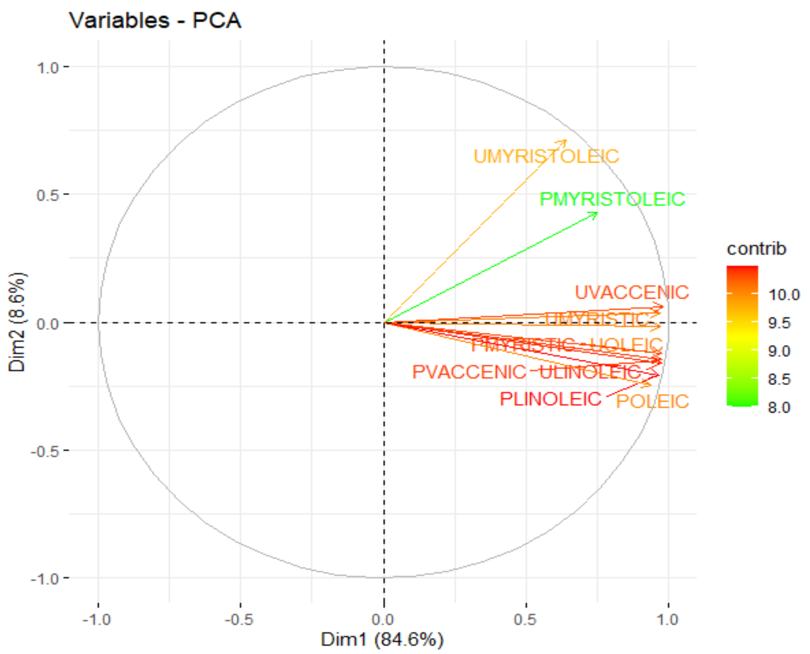


Figure 3: principal component analysis (PCA.)



In this investigation, myristic acid, a long-chain saturated fatty acid (14:0), was the third most prevalent fatty acid in rice samples. This fatty acid is known to cause fat accumulation in the body, yet it is also suitable for cardiovascular health (Verruck *et al.*, 2019). The ratio of saturated fat to simple dietary carbohydrates in the diet considerably impacts this behaviour (Ruiz-Nez *et al.*, 2016). Myristic acid has a direct role in post-translational protein modifications and mechanisms that regulate critical metabolic processes in the human body (Legrand & Rioux, 2015; Ruiz-Nez *et al.*, 2016). According to Dabadie *et al.*, (2005), moderate consumption of myristic acid increases omega-3 long-chain fatty acid content in plasma phospholipids, which may enhance human cardiovascular health indices. Myristic acid also has immunomodulatory effects by boosting a particular protein implicated in macrophage activation in mice with high myristic acid consumption (Hubbard *et al.*, 1996; Verruck *et al.*, 2019). Vaccenic acid (VA) (t11-octadecenoic acid) is a positional and geometric isomer of oleic acid (c9-octadecenoic acid) and the most abundant Trans monoene in ruminant fats (50-80% of total Trans content) (Lock *et al.* 2004; Field *et al.*, 2009). In ruminants, rodents, and humans, dietary VA can be desaturated to cis-9, trans-11-conjugated linoleic acid (c9,t11-CLA) (Santora *et al.*, 2000; Turpeinen *et al.*, 2002; Field *et al.*, 2009).

Oleic acid is a monounsaturated fatty acid that occurs naturally in various foods, mainly vegetable oils. Because of its established health benefits, it is also a possible element in processed functional meals (Igor, 2014). However, because of the high-calorie content, it is not advised to increase the consumption of specific fats but rather to replace other lipids with oleic acid. It is widely accepted that replacing saturated fats in the diet with oleic acid or other unsaturated fats helps maintain normal blood cholesterol levels. Various other effects have also been studied, including modulation of inflammatory markers, blood pressure, insulin sensitivity, gastrointestinal -Functions, and even multiple cancers (Igor, 2014).

Fat quality is typically determined by the percentage or quantity of saturated fatty acids (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA) (Hudson, 1992). PUFAs are said to provide various health benefits, including decreasing cholesterol, lowering the risk of cardiac arrhythmias, lowering blood pressure, avoiding gestational diabetes, and improving joint health (relieving arthritis). Both omega-3 and omega-6 PUFAs are precursors to hormone-like compounds that play important roles in a variety of biological and biochemical processes in the human body (Achidi et al., 2021). They are required for the production of prostaglandins, thromboxanes, prostacyclins, and leukotrienes, as well as for cholesterol transport and oxidation. PUFAs from both the n-6 and n-3 families are essential components of all cell membrane phospholipids. Polyunsaturated fatty acids (PUFA) from omega-6 are precursors to a variety of key inflammatory mediators (Achidi et al., 2021). An intermediate arachidonic acid can proceed through the cyclooxygenase pathway, which produces prostaglandins and thromboxanes, or the lipoxygenase pathway, which produces leukotrienes (Hanna and Hafez 2018). The saturated, monounsaturated, and polyunsaturated fatty acids found in the rice samples were myristic, oleic, vaccenic, and linoleic, in that order. Prospective epidemiological investigations in broad populations have demonstrated that dietary linoleic acid is associated with a lower risk of cardiovascular disease (Farvid et al., 2014). As a result, the paradigm that linoleic acid, an omega-6 PUFA, is cardio-protective was established. MUFAs serve an essential function in human nutrition because they minimise the risk of arteriosclerosis due to their hypo cholesterolemic action.

4.0 Conclusion

Our study revealed that all of the studied Abakaliki rice landraces are a source of dietary fatty acid in the diet of local populaces. The predominant fatty acids in the selected Abakaliki rice landraces include myristic, myristeolic, oleic, vaccenic, and linoleic. Furthermore, the selected Abakaliki parboiled rice samples have a higher percentage of these fatty acids than the un-parboiled rice samples. Our research has proven that rice parboiling, which is popular among Abakaliki rice farmers, enhances the fatty acid content of these samples. Compared to the myristic fatty acid, the only saturated fatty acid in these samples, the dietary fatty acid compositions of this study sample contain a higher percentage of unsaturated fatty acids. As a result, it is insignificant compared to the saturated fatty acids found in parboiled and un-parboiled Abakaliki rice. Therefore, these rice landraces could be regarded as safe to consume.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Abbas, A., Murtaza, S., Aslam, F., Khawar, A., Rafique, S., & Naheed, S. (2011). Effect of Processing on Nutritional Value of Rice (Oryza sativa). *World Journal of Medical Science*, 6.
2. Achidi, A., Tiencheu, B., Fehnui, A., Tenyang, N., Ngongang, T., Flore, E., D.R, F., Tonfack Djikeng, F., & Fabrice. (2021). Physicochemical Properties and Lipid Profile of Two Varieties of Raw and Parboiled Cameroonian Ndop Rice (Oryza sativa) Bran Oil: Effect of Oven Drying of the Bran on the Oil Chemical Properties and Oil Yields. *RIET-IJSET International Journal of Science Engineering and Technology, 8,* 2348-7968.
3. Alexa-Stratulat, T., Luca, A., descu, M., Bohotin, C. R., & Alexa, I. D. (2017). Nutritional Modulators in Chemotherapy-Induced Neuropathic Pain. In R. R. Watson & S. Zibadi (Eds.), *Nutritional Modulators of Pain in the Aging Population* (pp. 9-33). Academic Press.
4. Ballantyne, C. M. (2014). *Clinical Lipidology: A Companion to Braunwald's Heart Disease - 2nd Edition* (2nd ed.). Elsevier.

5. Bhattacharya, K. R. (2004). *Cereals & Grains Association* (E. T. Champagne, Ed. 3rd ed.). St. Paul.
6. Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology, 37*(8), 911-917.
7. Bryant, R. J., & McClung, A. M. (2011). Volatile profiles of aromatic and non-aromatic rice cultivars using SPME/GC–MS. *Food Chemistry, 124*(2), 501-513.
8. Cadoni, P., & Angelucci, F. (2019). Analysis of incentives and disincentives for rice in Nigeria. *Gates Open Research, 3*(643).
9. Caiming, L., Yuxian, Y., Di, C., Zhengbiao, G., Yuzhu, Z., Tod, P. H., Xiaofeng, B., Yan, H., Li, C., & Zhaofeng, L. (2021). A systematic review of rice noodles: Raw material, processing method and quality improvement. *Trends in food science & technology, 107*, 389-400.
10. Chukwu, O., & Oseh, F. J. (2009). Response of nutritional contents of rice (Oryza sativa) to parboiling temperatures. *American-Eurasian Journal of Sustainable Agriculture, 3*(3), 381-387.
11. Dabadie, H., Peuchant, E., Bernard, M., LeRuyet, P., & Mendy, F. (2005). Moderate intake of myristic acid in sn-2 position has beneficial lipidic effects and enhances DHA of cholesteryl esters in an interventional study. *The Journal of Nutritional Biochemistry, 16*(6), 375-382.
12. Danbaba, N., Nkama, I., Badau, M. H., Ukwungwu, M. N., Maji, A. T., Abo, M. E., H, H., Fati, K. I., & Oko, A. O. (2014). Optimization of Rice Parboiling Process for Optimum Head Rice Yield: A Response Surface Methodology (RSM) Approach. *International Journal of Agriculture and Forestry, 4*(3), 154-165.
13. Deb, D. (2017). Folk Rice Varieties, Traditional Knowledge and Nutritional Security in South Asia. *Agroecology, Ecosystems, and Sustainability in the Tropics* (G. Poyyamoli (ed.), Agroecology, Ecosystems, and Sustainability in the Tropics © Studera Press, 2017).
14. Dixon, W. R., Morales-Contreras, B. E., Kongchum, M., Xu, Z., Harrell, D., Moskowitz, H. R., & Wicker, L. (2020). Aroma, Quality, and Consumer Mindsets for Shelf-Stable Rice Thermally Processed by Reciprocal Agitation. *Foods 9*(11), E1559.
15. Dutta, H., & Mahanta, C. (2012). Effect of hydrothermal treatment varying in time and pressure on the properties of parboiled rices with different amylose content. *Food Research International, 49*, 655-663.
16. EFSA Panel on Dietetic Products, N. A. (2012). Scientific Opinion on the Tolerable Upper Intake Level of eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and docosapentaenoic acid (DPA). *EFSA Journal, 10*(7), 2815.
17. Elechi, J. O. G., Nwiyi, I. U., & Adamu, C. S. (2022). *Global Food System Transformation for Resilience*. IntechOpen.
18. FAOSTAT. (2020). *World Food and Agriculture - Statistical Yearbook 2020*. FAO. http://www.fao.org/documents/card/en/c/cb1329en.
19. Farvid, M. S., Ding, M., Pan, A., Sun, Q., Chiuve, S. E., Steffen, L. M., Willett, W. C., & Hu, F. B. (2014). Dietary linoleic acid and risk of coronary heart disease: a systematic review and meta-analysis of prospective cohort studies. *Circulation, 130*(18), 1568-1578.
20. Field, C. J., Blewett, H. H., Proctor, S., & Vine, D. (2009). Human health benefits of vaccenic acid. *Applied Physiology, Nutrition, and Metabolism 34*(5), 979-991.
21. Gutierrez, N. (2009). *Waldraw's Perspectives in nutrition* (8 ed.). McGraw-Hill.
22. Hanna, V. S., & Hafez, E. A. A. (2018). Synopsis of arachidonic acid metabolism: A review. *Journal of Advanced Research, 11*, 23-32.

23. Hubbard, N. E., Socolich, R. J., & Erickson, K. L. (1996). Dietary myristic acid alters acylated proteins in activated murine macrophages. *The Journal of Nutrition*, *126*(6), 1563-1570.
24. Hudson, B. J. F. (1992). *Biochemistry of Food Proteins* (B. J. F. Hudson, Ed.). Springer US.
25. Igor, P. (2014). Oleic Acid and Its Potential Health Effects. In *Oleic Acid: Production, Uses and Potential Health Effects – Nova Science Publishers* (pp. 35-50). Nova Science.
26. IndexMundi. Milled Rice Domestic Consumption by Country in 1000 MT - Country Rankings.https://www.indexmundi.com/agriculture/?commodity=milledrice&graph=domestic-consumption
27. IRRI (2008) Rice Knowledge Bank. http://www.knowledgebank.irri.org/
28. Jannasch, A., & Wang, Y.-J. (2020). Development of a limited-water soaking method on the fortification of rice with calcium and iron by parboiling. *Journal of Cereal Science*, *94*, 103014.
29. Kan, A. (2015). Characterization of the Fatty Acid and Mineral Compositions of Selected Cereal Cultivars from Turkey. *Records of Natural Products*, *9*, 124-134.
30. Kaur, A., Bhise, S., & Kaur, M. (2020). Hydrothermal treatments for paddy to improve physicochemical quality of brown rice. *Journal of Microbiology, Biotechnology and Food Sciences*, *9*(5), 913-926.
31. Kimura, T., Bhattacharya, K. R., & Ali, S. Z. (1993). Discoloration Characteristics of Rice during Parboiling (I). *Nogyo Shisetsu (Journal of the Society of Agricultural Structures, Japan)*, *24*(3), 153-160.
32. Koh, E., & Surh, J. (2016). Parboiling improved oxidative stability of milled white rice during one-year storage. *Food Science and Biotechnology*, *25*(4), 1043-1046.
33. Kromhout, D., Menotti, A., Bloemberg, B., Aravanis, C., Blackburn, H., Buzina, R., Dontas, A. S., Fidanza, F., Giampaoli, S., & Jansen, A. (1995). Dietary saturated and trans fatty acids and cholesterol and 25-year mortality from coronary heart disease: the Seven Countries Study. *Preventive Medicine*, *24*(3), 308-315.
34. Kumar, A., Lal, M. K., Nayak, S., Sahoo, U., Behera, A., Bagchi, T. B., Parameswaran, C., Swain, P., & Sharma, S. (2022). Effect of parboiling on starch digestibility and mineral bioavailability in rice (Oryza sativa L.). *LWT*, *156*, 113026.
35. Kumar, A., Sharma, N., Kumar, K., Kumar, A., Bora, S., & Bisht, S. (2021). Estimation of amino acids in pigmented rice landraces from Kumaun region of Uttarakhand. *10*, 69-79.
36. Legrand, P., & Rioux, V. (2015). Specific roles of saturated fatty acids: Beyond epidemiological data. *European Journal of Lipid Science and Technology*, *117*(10), 1489-1499.
37. Linares, O. F. (2002). African rice (Oryza glaberrima): History and future potential. *Proceedings of the National Academy of Sciences*, *99*(25), 16360-16365.
38. Lock, A. L., Corl, B. A., Barbano, D. M., Bauman, D. E., & Ip, C. (2004). The Anticarcinogenic Effect of trans-11 18:1 Is Dependent on Its Conversion to cis-9, trans-11 CLA by Desaturase in Rats. *The Journal of Nutrition*, *134*(10), 2698-2704.
39. Lu, L. W., Monro, J., Lu, J., & Rush, E. (2018). The Effect of Cold Treatment of Parboiled Rice with Lowered Glycaemic Potency on Consumer Liking and Acceptability. *Foods 7*(12), E207.
40. Marti, A., Caramanico, R., Bottega, G., & Pagani, M. A. (2013). Cooking behavior of rice pasta: effect of thermal treatments and extrusion conditions. *LWT - Food Science and Technology*, *54*(1), 229-235.

41. Mondal, P., Datta, S., & Deb, D. (2021). Agronomic and nutraceutical properties of indigenous rice varieties. *A Handbook of Agriculture and Plant Sciences*, 71-92.
42. Nugent, A. P. (2005). Health properties of resistant starch. *Nutrition Bulletin*, *30*(1), 27-54.
43. Odenigbo, M., Ngadi, M., Ejebe, C., Woin, N., & Ndindeng, S. A. (2014). Physicochemical, Cooking Characteristics and Textural Properties of TOX 3145 Milled Rice. *Journal of Food Research*, *3*, 82.
44. Oli, P., Ward, R., Adhikari, B., & Torley, P. (2014). Parboiled rice: Understanding from a materials science approach. *Journal of Food Engineering*, *124*, 173-183.
45. Olumuyiwa, A. O. (2014). *Effect of Processing Conditions on Physical, Chemical, Cooking, and Sensor Properties of Ofada Rice (Oryza Sativa L) Grain And Flakes* [Thesis] http://ir.library.ui.edu.ng/handle/123456789/201
46. Parnsakhorn, S., & Noomhorm, A. (2008). Changes in Physicochemical Properties of Parboiled Brown Rice during Heat Treatment. *Agricultural Engineering International*, *10*.
47. Patindol, J., Fragallo, L., Wang, Y.-J., & Durand-Morat, A. (2017). Impact of Feedstock, Parboiling Condition, and Nutrient Concentration on Simultaneous Fortification of Two U.S. Long-Grain Rice Cultivars with Iron and Zinc. *Cereal Chemistry*, *94*(6), 984-990.
48. Poddar-Sarkar, M. (1996). The fixative lipid of tiger pheromone. *Journal of Lipid Mediators and Cell Signalling*, *15*(1), 89-101.
49. Rathna, P. T. S., Eliazer Nelson, A. R. L., Ravichandran, K., & Antony, U. (2019). Nutritional and functional properties of coloured rice varieties of South India: a review. *Journal of Ethnic Foods*, *6*(1), 11.
50. Ray, S., Deb, D., & Sarkar, M. (2021). Colour based nutraceutical potentiality of some traditional rice (Oryza sativa ssp. indica L.) varieties of India. *Indian Journal of Natural Products and Resources*, *12*, 153-157.
51. Ray, S., Deb, D., Nandy, A., Basu, D., Aich, A., Tripathi, S., Roy, S. S., & Sarkar, M. P. (2021). Rare and neglected rice landraces as a source of fatty acids for undernourished infants. *Current Science*, *121*(5), 660.
52. Rocha-Villarreal, V., Serna-Saldivar, S. O., & García-Lara, S. (2018). Effects of parboiling and other hydrothermal treatments on the physical, functional, and nutritional properties of rice and other cereals. *Cereal Chemistry*, *95*(1), 79-91.
53. Roe, B., Bender, K., & Qi, D. (2020). The Impact of COVID-19 on Consumer Food Waste. *Applied Economic Perspectives and Policy*, *43*.
54. Rosedale, R. E. (2017). *Omega-3 fatty acid nutraceutical composition and optimization method* (US9610298B1).S.United.https://patents.google.com/patent/US9610298B1/en?oq=9610298.
55. Roy, K., & Divyanshi, W. (2019). Half of the world's poor live in just 5 countries [Data blog]. *World Bank blogs*. https://blogs.worldbank.org/opendata/half-world-s-poor-live-just-5-countries
56. Ruiz-Núñez, B., Dijck-Brouwer, D. A. J., & Muskiet, F. A. J. (2016). The relation of saturated fatty acids with low-grade inflammation and cardiovascular disease. *The Journal of Nutritional Biochemistry*, *36*, 1-20.
57. Ruskin, F.R.. (1996). *Lost Crops of Africa*. (Bostid, Ed. Vol. 1). National Academies Press.
58. Santora, J. E., Palmquist, D. L., & Roehrig, K. L. (2000). Trans-vaccenic acid is desaturated to conjugated linoleic acid in mice. *The Journal of Nutrition*, *130*(2), 208-215.

59. Shen, Y., Jin, L., Xiao, P., Lu, Y., & Bao, J. (2009). Total phenolics, flavonoids, antioxidant capacity in rice grain and their relations to grain color, size and weight. *Journal of Cereal Science, 49*(1), 106-111.
60. Taddei, F., Galassi, E., Nocente, F., & Gazza, L. (2021). Innovative Milling Processes to Improve the Technological and Nutritional Quality of Parboiled Brown Rice Pasta from Contrasting Amylose Content Cultivars. *Foods, 10*(6), 1316.
61. Taleon, V., Gallego, S., Orozco, J. C., & Grenier, C. (2020). Retention of Zn, Fe and phytic acid in parboiled biofortified and non-biofortified rice. *Food Chemistry, 8,* 100 - 105.
62. Tian, S., Nakamura, K., & Kayahara, H. (2004). Analysis of Phenolic Compounds in White Rice, Brown Rice, and Germinated Brown Rice. *Journal of Agricultural and Food Chemistry, 52*(15), 4808-4813.
63. Turpeinen, A. M., Mutanen, M., Aro, A., Salminen, I., Basu, S., Palmquist, D. L., & Griinari, J. M. (2002). Bioconversion of vaccenic acid to conjugated linoleic acid in humans. *The American Journal of Clinical Nutrition, 76*(3), 504-510.
64. Uyeh, D. D., Asem-Hiablie, S., Park, T., Kim, K., Mikhaylov, A., Woo, S., & Ha, Y. (2021). Could Japonica Rice Be an Alternative Variety for Increased Global Food Security and Climate Change Mitigation? *Foods, 10*(8), 18 - 69.
65. Verruck, S., Balthazar, C. F., Rocha, R. S., Silva, R., Esmerino, E. A., Pimentel, T. C., Freitas, M. Q., Silva, M. C., da Cruz, A. G., & Prudencio, E. S. (2019). Dairy foods and positive impact on the consumer's health. *Advances in Food and Nutrition Research, 89*, 95-164.
66. Woolf, C. J., & Salter, M. W. (2000). Neuronal plasticity: increasing the gain in pain. *Science (New York, N.Y.), 288*(5472), 1765-1769.
67. WorldBank. (2021). Nutrition Country Profiles. *World Bank.* https://www.worldbank.org/en/topic/health/publication/nutrition-country-profiles.
68. Yanjie, X., Yining, Y., Shuhong, O., Xiaoliang, D., Hui, S., Shukun, J., Shichen, S., & Jinsong, B. (2018). Factors Affecting Sensory Quality of Cooked japonica Rice. *Rice Science, 25*(6), 330-339.
69. Zhang, W., Cheng, B., Zeng, X., Tang, Q., Shu, Z., & Wang, P. (2022). Physicochemical and Digestible Properties of Parboiled Black Rice with Different Amylose Contents. *Frontiers in Nutrition, 9*.
70. Zohoun, E. V., Ndindeng, S. A., Soumanou, M. M., Tang, E. N., Bigoga, J., Manful, J., Sanyang, S., Akissoe, N. H., & Futakuchi, K. (2018). Appropriate parboiling steaming time at atmospheric pressure and variety to produce rice with weak digestive properties. *Food Science & Nutrition, 6*(4), 757-764.