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Starter-culture to improve the quality of cereal-based fermented foods: trends in selection and application

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Cereals are the most important food crop globally. Greater part of cultivated cereals is subjected to fermentation by the best adapted strains from a contaminating mix of microorganisms, generating varieties of foods and beverages that are inconsistent in quality. Recently, fresh demands for quality consistency, stability, safety and specific health benefits have been placed on fermented cereal products. Accumulated scientific evidences show that careful selection and use of autochthonous multifunctional microbial strains can contribute to predictable and reproducible improvement of the safety, nutritional, organoleptic and functional quality of fermented cereal foods. We highlight trendy criteria to prospect for native multifunctional strains from indigenous cereal fermented products and examine their application as starter cultures with specific focus on the improvement of cereal substrates to meet contemporary market demands.

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Introduction

Cereals remain the most important food crop with an estimated global production of 2500 million tonnes in 2015 [1]. They are important sources of calorie, vitamins, minerals, dietary fiber, protein and bioactive compounds [2]. However, the optimal utilization of cereals is a challenge because of the unappealing nature of the grains, presence of anti-nutritional factors and poor digestibility and deficiency of some nutrients [3,4]. Epidemiological evidences link the burden of malnutrition-related diseases, including stunted growth and anemia to high dependence on unfortified cereal products [5].

Fermentation offers a simple and economical means to improve the nutritional value and sensory attributes of cereal grains [6•]. Incidentally, a greater part of cultivated cereals are subjected to fermentation [7], generating varieties of beverages, dough and gruels majorly from barley (*Hordeum vulgare*), maize (*Zea mays*), millet (*Pennisetum glaucum*), oat (*Avena sativa*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*) and wheat (*Triticum* sp.). For a broad list of cereal fermented food products, see Blandino *et al.* [3] and Waters *et al.* [2]. They are widely consumed, contributing significantly to the safety and diversity of human diet, particularly in Africa and Asia. Indigenous cereal fermented products are barely known outside the regions where they are produced by the art of spontaneous and traditional fermentation. The best adapted strains from a mix of microorganisms (lactic acid bacteria, yeasts and moulds) determine the stability, safety and overall quality of the products [8]. This is responsible for the inconsistencies in qualities and high risk for failure of the spontaneously fermented products [9].

Over the last two decades, expanding population, urbanization, changes in consumer lifestyle and increased awareness of consumer health have placed demands for consistency in quality, stability, safety and specific health benefits on fermented cereal products. Accumulated scientific evidences have shown that careful selection and use of autochthonous microbial strains with inherent desirable characteristics can contribute to a predictable and reproducible improvement of the different quality attributes of fermented cereals. The choice of strain(s) has a critical impact on the specific function and novelty of the cereal fermented product [10••]. In this review, we highlight trendy criteria to prospect for native multifunctional strains from indigenous cereal fermented products and examine their application as starter cultures with specific focus on the improvement of cereal substrates to meet contemporary market demands.

Selection criteria of multifunctional strains for cereal fermentation

Safety

Species of lactic acid bacteria (LAB) and yeasts that are expected to be selected for cereal bioprocessing should be Generally Recognized as Safe (GRAS) and Presumed to be Safe (QPS) based on evaluations by the Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), respectively. No harm will result from the inclusion of such strains in foods [8]. In demonstrating the safety of a potential starter culture for cereal products, it is imperative to identify such species in the list of microorganisms with GRAS and/or QPS status by employing appropriate taxonomical tools. A polyphasic approach to taxonomy, analyzing both genotypic and phenotypic data remains more reliable for the identification of potential starter strains isolated from cereals substrates. This approach was employed in several studies where fermented cereal products such as *burukutu*, *kunu zaki*, *ogi*, sourdough, *togwa*, were examined for potential starter strains of LAB and yeasts [10••,11–15,16•].

Fermentative activity

Potential starter strains of LAB and yeasts must metabolize wide spectrum of carbohydrates in cereals, tolerate typical stress conditions during cereal fermentation and rapidly secrete inhibitory metabolites. These features are critical for the competitive advantage of starter, ensuring process control and product predictability [12]. Although strain-specific, LAB strains from wheat bran sourdough metabolized wide spectrum of carbohydrate and rapidly grew by a log order up to three units after 8 hours of fermentation [10••]. Perricone *et al.* [13] screened yeast strains isolated from Altamura sourdough for tolerance to stress conditions in cereal processing and products. They identified six strains of *Candida humilis* and *Saccharomyces cerevisiae* that showed high growth index (>75%) at 4% NaCl concentration.

In addition, the performance of LAB and yeasts intended as starter culture is connected to the rate of acid and CO_2 production respectively [13,16•]. Acids inhibit unwanted microbiota and enhance activity of endogenous enzymes in cereals [17,18•]. Diversity in the rate of acidification was revealed in LAB strains isolated from different cereal substrates and fermented products; fermented millet dough [16•], wheat bran sourdough [10••] and wheat flour [12]. Variation in CO_2 production, indicated as leavening activity was demonstrated by yeast species isolated from Altamura sourdough [13].

Organoleptic properties

Sensory impression is the primary motivation to consumer choice of foods [19]. Strains of LAB and yeasts metabolize the organic compounds in cereal substrate through pathways that generate unique flavor-active non-volatile and volatile compounds [20,21•]. The major aroma and flavor-active compounds described in LAB and yeasts include esters, carbonyls and organic acids [12,21•,22]. The metabolic profiling of 11 technological relevant LAB strains isolated from wheat flour revealed different concentrations of the 18 volatile compounds released into wheat fermentation broth [12]. Ferri *et al.* [6•] also demonstrated the distinctions in the profiles of volatile molecules released by *Lb. plantarum* strains into two different varieties of wheat flour-fermented dough. The major compounds released by potential starter strain into the fermentation medium are safe for food application and they possess appealing flavors and odors [Flavor and Extract Manufacturers Association; URL: http://www.fema.com; The Good Scent Company; URL: http://www.thegoodscentscompany.com/data/rw1009101.html].

The evaluation of five yeast strains; *Pichia kluyveri* LKC17, *Pichia kudriavzevii* OG32, *P. kudriavzevii* ROM11, *Issatchenkia orientalis* OSL11 and *Candida tropicalis* BOM21 in a chemically defined fermentation broth (Yeast Peptone Dextrose medium) revealed species and strain-specificity in the variety and relative concentration of the volatile compounds identified in the respective broths. *P. kudriavzevii* OG32, *P. kluyveri* LKC17 and *I. orientalis* OSL11 produced the highest concentration of esters (17.38%), organic acids (35.47%) and carbonyls (46.95%) respectively [OR Ogunremi *et al.*, unpublished].

The intensive exploration for amylolytic and exopolysaccharide-producing (EPS) LAB and yeasts remains sustained due of their potentials to improve the rheological properties of fermented cereal foods without safety concerns. Amylolytic strains contribute to the maintenance of liquid consistency of cereal-based gruels. High EPS yielding species of LAB belong to *Lactobacillus*, *Leuconostoc*, *Pediococcus* and *Wessiella* genera [23,24]. *Lb. plantarum* and *P. pentosaceus* were the major EPS producers out of the LAB strains isolated from wheat-bran [10••]. The *Lb. plantarum* strain tested produced EPS in presence of different carbon sources, including starch, the most abundant carbon source in cereal products [10••]. Majority (85.6%) of the 176 *Lb. fermentum* strains isolated from millet sourdough produced EPS [16•]. EPS producers have the potentials to improve the texture, feel, consistency and stability of fermented cereal foods [21•].

Antagonistic properties (bioprotective microbes)

Antibacterial fermentative microbes and secondary metabolites have been extensively reported as potential substitutes for synthetic compounds to guarantee the stability and safety of cereal fermented products [15,25,26]. However, fungal contamination of cereal products remains a major source of loss and public health concern [27••]. Studies of antifungal strains for food application are still at an early stage. In the last couple of years, strains and metabolites with antifungal activities have been isolated and characterized. Antifungal LAB genera include *Lactobacillus*, *Leuconostoc* and *Pediococcus* [10••,18•,27••,28]. Manini *et al.* [10••] reported different degrees of *in-vitro* inhibition of *Aspergillus oryzae* and *A. niger* by strains of *Lb. plantarum*, *Lb. curvatus*, *Lb. brevis*, *Ln. mesenteroides* and *P. pentosaceus*.

Although the active compounds have not been fully elucidated, the antifungal effect of LAB strains is suggested to be due to the synergistic or additive interaction of a cocktail of metabolites, including cyclic dipeptides, organic acids and fatty acids [28]. Axel *et al.* [28] revealed