



Food microbial biodiversity and “microbes of protected origin”

Vittorio Capozzi and Giuseppe Spano*

Department of Food Science, Foggia University, Foggia, Italy

*Correspondence: g.spano@unifg.it

TYPICAL FOOD AND GEOGRAPHICAL INDICATIONS

Over the past decades, traditional food systems have evolved from poorly coordinated networks to globalized complexes of regulated trade, and the geographical indications (GIs) agro-food market size is approximately \$50 billion. Belonging to the intellectual property law as collective property rights, the “GI is a sign used on goods that have a specific geographical origin and possess qualities, reputation, or characteristics that are essentially attributable to that place of origin” (World Intellectual Property Organization (WIPO), 2011). The global impact of “GI” is widely testified through the scientific, social, and economic importance of traditional foods (World Intellectual Property Organization (WIPO), 2011; World Trade Organization (WTO), 2011). In fact, GIs are known to be the earliest type of trademarks. From an edible perspective, this concept is simply and well presented by Bisson et al. (2002): “consumers expect wine from a particular region to possess unique qualities that differentiate it from other wines of the same varietal from other regions.” The GI system is based upon the concept of “terroir,” a French word used to describe all geographical aspects of the environment, including the climate, geology, cultivar, human, technical, and cultural practices (and the interactions of these factors) that can influence local production. The form of protection is generally in accordance with signed accords and treaties such as the TRIPS (Trade-Related aspects of Intellectual Property Rights) Agreement or the Lisbon Agreement. Even if at the national level, they are specifically protected by a variety of laws or instruments. For instance, in the European Union (EU), GIs for agricultural products and foodstuffs are protected by (EC Regulation 510/2006, 2006; these rules do not apply to wine-sector products which are cov-

ered by separate rules; Kireeva, 2011) and, according to estimates, it represents a total annual sales volume of approximately €14 billion (Italy, 8.9; France, 2.3; Germany, 2.0; Spain, 0.9; Profeta et al., 2009).

FOOD MICROBIOLOGY AND GEOGRAPHICAL INDICATIONS

The importance of fermented foods in the context of GIs is particularly relevant, due to the historic, cultural, and traditional significance (Battcock and Azam-Ali, 1998; Holtzman, 2006). For example, without considering wines, the percentages of the following food categories in the EU were: 37% cheeses, 20% beer, 16% meat products, 4% fruit and vegetables, 4% bakery products, biscuits, confectionery (EU Newsletter, 2010). The fermentation of foods, the “oldest biotechnology,” has been an effective form of food preservation for millennia (Ross et al., 2002) and, as sharply observed by Suzzi (2011), the knowledge on how wild strains become domesticated represents a common research priority for food microbiologists (for an overview of the principal selective processes involved in this phenomenon see Suzzi, 2011). Historically, food fermentations were based on naturally occurring microorganisms, and in the framework of industrial food production, food bio-preservation is usually achieved with the necessary amount of selected strains (starter cultures) to ensure consistency, safety, and quality of the final product. Microbial ecology of food fermentations continues to play a crucial and complex role in fermented foods. It is widely recognized that the emergence of a given microbiota in a food matrix influences the global quality and uniqueness of the final product. The study of microbial biodiversity related to food GIs has been receiving growing scientific attention and world interest (e.g., Benito et al., 2007; De Angelis et al., 2008; Ercolini et al., 2008; Gala et al., 2008; Gullo and Giudici, 2008; Capozzi et al., 2010;

Csoma et al., 2010; Valmorri et al., 2010; Cocolin et al., 2011; Cordero-Bueso et al., 2011; Tristezza et al., 2011). In GIs product specification, the microbial attributes are recognized as geographical (territorial) traits and/or as a part of production characteristics (list of autochthonous species and strains, preparation of the natural starter culture, use of specific commercial starter cultures, the chemico-physical foodstuff factors responsible of microbial development). It is important to underline that the commercial starter cultures use might lead to losses in “unique qualities,” while the pursuit of wild natural fermentations (natural starter culture) can result in fermentation arrests and/or the production of undesired metabolites responsible for food depreciation or human toxicity.

MICROBES OF PROTECTED ORIGIN

Is it time for a GI regimen in food microbiology? Do microbial resources belong to “terroir” aspects? We argue that criteria on microbial resources employed in GI fermented foods should be clearly legislatively defined in the framework of policies on protected GIs. In fact, plant varieties and local animal breeds are not the only geographical attributes. GI fermented foods are also based on other forms of biodiversity, ranging from traditional knowledge to microbial ecosystems. Even if the real characteristics and dimensions of strains of *terroir* (Renouf et al., 2006) remain a scientifically open question, it appears that selective pressure from environmental parameters and processing conditions in addition to the geographical determinants contribute to the domestication process (Suzzi, 2011). Collectively, the role of microbial biodiversity for different food products and the repercussions on GI unique traits is clear. The technical procedures in production of GI fermented foods might comprise a list of microbial strains representing the “virtuous” microbial biodiversity of a specific environment and for a

given food production. The autochthonous strains should have genotypic/phenotypic characterization in the context of application and deposited in microbial collections. Different cellular biomarkers (selected by coupling different-omics strategies and classical microbiology) should be used in function of food matrices (nutrient potentials and stress conditions) and of desired fermentative behavior. Mainly, the biomarker should be quantitatively correlated with stress adaptive behavior (den Besten et al., 2010; Abee et al., 2011) and fermentative performances. The biomarker strategy accelerates laboratory screening and, followed by the necessary industrial scale-up activities, leads to design robustness and efficient starter culture formulation for a given GIs production. An example of biomarker is the mRNA abundance of the gene encoding the only small heat shock protein in the malolactic bacterium *Oenococcus oeni* (Coucheney et al., 2005; Capozzi et al., 2010). The transcript level was positively correlated with adaptation to the harsh wine environment and with malolactic performance (Coucheney et al., 2005; Capozzi et al., 2010). Starting from the selected strains, GI fermented food producers might formulate their own multi-strains starter culture. From this point of view, a concrete example is represented by Roquefort product specifications: “Before it is pressed, the raw cheese is cultured with spores of *Penicillium roqueforti* [...] The *Penicillium roqueforti* culture is added either in liquid form at the renneting stage or in powder form when the curd is placed in the mold [...] The cheese is left exposed in caves in Roquefort-sur-Soulzon, located in the scree of the Combalou mountain, for the length of time needed for the *Penicillium roqueforti* to develop successfully” (Official Journal of the European Union, C 298, 11/12/2007, pp. 28–33). “The inoculation is done with powders and cultures of *Penicillium roqueforti* prepared from traditional strains isolated in the microclimate of the caves in the delimited area of the town of Roquefort-sur-Soulzon defined in the Article 6” (Ministère de l’agriculture et de la pêche. Décret du 22 janvier 2001 relatif à l’appellation d’origine contrôlée “Roquefort.” J.O. Numéro 21 du 25 janvier 2001 page 1283). Summarizing, in the case of Roquefort, microbial resources were considered as part of the geographical attrib-

utes, belonging to the raw material (even if strain names are not specified, remaining a certain level of unclear microbial information), and practices connected to microbial management are clearly defined.

MICROBES OF PROTECTED ORIGIN AND ORGANIC PRODUCTION

Also the organic agro-food system has been strongly evolved in the last two decades. The proposed innovations should also represent an economic, scientific, and environmental sustainable approach to assure the safety of organic fermented food, respecting an equilibrated integration of traditional dynamics with advanced biotechnologies. As a matter of fact, when the organic food production requires a fermentation step, field-based evidences indicate that an increasing number of manufacturers rely on wild microbial consortia. They follow the idea that “synthetic pesticides and fertilizers” are to “farming” as “commercial microbial starter cultures” are to “food fermentations.” Naturally, this productive behavior may lead to microbial production of toxic compounds, such as ochratoxin A, ethyl carbamate, and biogenic amines (Egmond et al., 2007; Spano et al., 2010; Pozo-Bayón et al., 2012). As the market for organic food continues to grow, the problem becomes more and more urgent. In this context, the food biotechnological scientific community should offer an organic-friendly solution able to reconcile organic viewpoint with safe food fermentations. Hence, the formulation and the production of a multi-strain microbial starter that mimics the natural diversity and function of the biotechnological processes might be a reliable alternative to organic uncontrolled fermentations, increasing the organoleptic qualities of production and minimizing the risk of foodborne pathogens, microbial toxic compound productions, and microbial spoilage.

PERSPECTIVES

The principal implication of a systems ecology perspective is the improvement of product “unique qualities” via an enhanced management of microbial biodiversity in food environments, maintaining a high attention to biological risks for human health and industrial exigencies of product standardization. Pertinent to this concern, we underline the reliable potential of a possible world driver of “glocal” innova-

tion in the sector of one of the “oldest” biotechnologies, like wine- or bread-making. With respect to technological transfer, this interdisciplinary (Max-Neef, 2005) innovation might lead to the development of opportunities for local research teams in microbial ecology and food microbiology, academic spin-off companies, bioentrepreneurs, and microbial collections. Hence, it would be an exciting opportunity of systemic design (Kuehr, 2007), distributed economies (Johansson et al., 2005), *ex situ* microbial biodiversity conservation (Gams, 2004), and microbial commons regimen (Dijkshoorn et al., 2010) in the knowledge-based bio-economy landscapes. Indeed, the proposed approach is coherent with the existing microbial patenting framework (Sekar and Kandavel, 2004; Webber, 2006), in fact a multi-strain starter culture essentially satisfies the patentable criteria. Finally, highlighting the idea that microbial biodiversity belongs to the geographical attributes of fermented food, we propose a possible concrete role of microbial resources in ethnobiology and ethnomedicine, in accordance with the consideration that human food chain and microorganisms represent a case of co-evolution (Guerzoni, 2010).

REFERENCES

- Abee, T., Wels, M., de Been, M., and den Besten, H. (2011). From transcriptional landscapes to the identification of biomarkers for robustness. *Microb. Cell Fact.* 10, S9.
- Battcock, M., and Azam-Ali, S. (1998). *Fermented Fruits and Vegetables. A Global Perspective*. FAO Agricultural Services Bulletin No. 134. Rome: Food and Agriculture Organization of the United Nations.
- Benito, M. J., Martín, A., Aranda, E., Pérez-Nevaldo, F., Ruiz-Moyano, S., and Córdoba, M. G. (2007). Characterization and selection of autochthonous lactic acid bacteria isolated from traditional Iberian dry-fermented salchichón and chorizo sausages. *J. Food Sci.* 72, M193–M201.
- Bisson, L. F., Waterhouse, A. L., Ebeler, S. E., Walker, M. A., and Lapsley, J. T. (2002). The present and future of the international wine industry. *Nature* 418, 696–699.
- Capozzi, V., Russo, P., Beneduce, L., Weidmann, S., Grieco, F., Guzzo, J., and Spano, G. (2010). Technological properties of *Oenococcus oeni* strains isolated from typical southern Italian wines. *Lett. Appl. Microbiol.* 50, 327–334.
- Cocolin, L., Dolci, P., and Rantsiou, K. (2011). Biodiversity and dynamics of meat fermentations: the contribution of molecular methods for a better comprehension of a complex ecosystem. *Meat Sci.* 89, 296–302.
- Cordero-Bueso, G., Arroyo, T., Serrano, A., Tello, J., Aporta, I., Vélez, M. D., and Valero, E. (2011). Influence of the farming system and vine variety on yeast communities associated with grape berries. *Int. J. Food Microbiol.* 145, 132–139.

- Coucheny, F., Desroche, N., Bou, M., Tourdot-Maréchal, R., Dulau, L., and Guzzo, J. (2005). A new approach for selection of *Oenococcus oeni* strains in order to produce malolactic starters. *Int. J. Food Microbiol.* 105, 463–470.
- Csoma, H., Zakany, N., Capece, A., Romano, P., and Sipiczki, M. (2010). Biological diversity of *Saccharomyces* yeasts of spontaneously fermenting wines in four wine regions: comparative genotypic and phenotypic analysis. *Int. J. Food Microbiol.* 140, 239–248.
- De Angelis, M., de Candia, S., Calasso, M. P., Faccia, M., Guinee, T. P., Simonetti, M. C., and Gobetti, M. (2008). Selection and use of autochthonous multiple strain cultures for the manufacture of high-moisture traditional Mozzarella cheese. *Int. J. Food Microbiol.* 125, 123–132.
- den Besten, H. M. W., Arvind, A., Gaballo, H. M. S., Moezelaar, R., Zwietering, M. H., and Abee, T. (2010). Short- and long-term biomarkers for bacterial robustness: a framework for quantifying correlations between cellular indicators and adaptive behavior. *PLoS ONE* 5, e13746. doi: 10.1371/journal.pone.0013746
- Dijkshoorn, L., De Vos, P., and Dedeurwaerdere, T. (2010). Understanding patterns of use and scientific opportunities in the emerging global microbial commons. *Res. Microbiol.* 161, 407–413.
- EC Regulation 510/2006. (2006). Council Regulation (EC) No 510/2006 of 20 March 2006 on the protection of geographical indications and designations of origin for agricultural products and foodstuffs. Official Journal L 093, 0012–0025. Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32006R0510:EN:NOT>
- Egmond, H. P., Schothorst, R. C., and Jonker, M. A. (2007). Regulations relating to mycotoxins in food. *Anal. Bioanal. Chem.* 389, 147–157.
- Ercolini, D., Frisso, G., Mauriello, G., Salvatore, F., and Coppola, S. (2008). Microbial diversity in natural whey cultures used for the production of Caciocavallo Silano PDO cheese. *Int. J. Food Microbiol.* 124, 164–170.
- EU Newsletter. (2010). *PDO and PGI Agricultural Products: A 14.2 Billion Euro Turnover for Over 800 Products*. European Commission Agriculture and Rural Development. Available at: http://ec.europa.eu/agriculture/quality/schemes/newsletter-2010_en.pdf
- Gala, E., Landi, S., Solieri, L., Nocetti, M., Pulvirenti, A., and Giudici, P. (2008). Diversity of lactic acid bacteria population in ripened Parmigiano Reggiano cheese. *Int. J. Food Microbiol.* 125, 347–351.
- Gams, W. (2004). “Ex situ conservation of microbial diversity,” in *Microorganisms in Plant Conservation and Biodiversity*, eds K. Sivasithamparama, K. W. Dixon, R. L. Barrett, and W. Gams (Dordrecht: Springer Netherlands), 269–283.
- Guerzoni, M. E. (2010). Human food chain and microorganisms: a case of co-evolution. *Front. Microbiol.* 1:106. doi: 10.3389/fmicb.2010.00106
- Gullo, M., and Giudici, P. (2008). Acetic acid bacteria in traditional balsamic vinegar: phenotypic traits relevant for starter cultures selection. *Int. J. Food Microbiol.* 125, 46–53.
- Holtzman, J. D. (2006). Food and memory. *Annu. Rev. Anthropol.* 35, 361–378.
- Johansson, A., Kisch, P., and Mirata, M. (2005). Distributed economies – a new engine for innovation. *J. Clean Prod.* 13, 971–979.
- Kireeva, I. (2011). How to register geographical indications in the European community. *World Patent Info.* 33, 72–77.
- Kuehr, R. (2007). Towards a sustainable society: United Nations University’s zero emissions approach. *J. Clean. Prod.* 15, 1198–1204.
- Max-Neef, M. A. (2005). Foundations of transdisciplinarity. *Ecol. Econ.* 53, 5–16.
- Pozo-Bayón, M. Á., Monagas, M., Bartolomé, B., and Moreno-Arribas, M. V. (2012). Wine features related to safety and consumer health: an integrated perspective. *Crit. Rev. Food Sci. Nutr.* 52, 31–54.
- Profeta, A., Baling, R., Schoene, V., and Wirsig, A. (2009). The protection of origins for agricultural products and foods in Europe: status quo, problems and policy recommendations for the Green Book. *J. World Intellect. Prop.* 12, 622–648.
- Renouf, V., Miot-Sertier, C., Strehaiano, P., and Lonvaud-Funel, A. (2006). The wine microbial consortium: a real terroir characteristic. *Int. J. Sci. Vigne Vin.* 40, 9–216.
- Ross, R. P., Morgan, S., and Hill, C. (2002). Preservation and fermentation: past, present and future. *Int. J. Food Microbiol.* 79, 3–16.
- Sekar, S., and Kandavel, D. (2004). The future of patent deposition of microorganisms? *Trends Biotechnol.* 22, 213–218.
- Spano, G., Russo, P., Lonvaud-Funel, A., Lucas, P., Alexandre, H., Grandvalet, C., Coton, E., Coton, M., Barnavon, L., Bach, B., Rattray, F., Bunte, A., Magni, C., Ladero, V., Alvarez, M., Fernández, M., Lopez, P., de Palencia, P. F., Corbi, A., Trip, H., and Lolkema, J. S. (2010). Biogenic amines in fermented foods. *Eur. J. Clin. Nutr.* 64, S95–S100.
- Suzzi, G. (2011). From wild strain to domesticated strain: the philosophy of microbial diversity in foods. *Front. Microbiol.* 2:169. doi: 10.3389/fmicb.2011.00169
- Tristezza, M., Vetrano, C., Bleve, G., Grieco, F., Tufariello, M., Quarta, A., Mita, G., Spano, G., and Grieco, F. (2011). Autochthonous fermentation starters for the industrial production of Negroamaro wines. *J. Ind. Microbiol. Biotechnol.* doi: 10.1007/s10295-011-1002-z
- Valmorri, S., Tofalo, R., Settanni, L., Corsetti, A., and Suzzi, G. (2010). Yeast microbiota associated with spontaneous sourdough fermentations in the production of traditional wheat sourdough breads of the Abruzzo region (Italy). *Antonie Van Leeuwenhoek* 97, 119–129.
- Webber, P. M. (2006). Patenting of microorganisms. *Nat. Rev. Drug Discov.* 5, 13.
- World Intellectual Property Organization (WIPO). (2011). *About Geographical Indications*. Available at: http://www.wipo.int/geo_indications/en/about.html
- World Trade Organization (WTO). (2011). *Geographical Indications*. Available at: http://www.wto.org/english/tratop_e/trips_e/gi_e.htm

Received: 19 August 2011; accepted: 10 November 2011; published online: 28 November 2011.

Citation: Capozzi V and Spano G (2011) Food microbial biodiversity and “microbes of protected origin”. *Front. Microbiol.* 2:237. doi: 10.3389/fmicb.2011.00237

This article was submitted to *Frontiers in Microbiotechnology, Ecotoxicology and Bioremediation*, a specialty of *Frontiers in Microbiology*.

Copyright © 2011 Capozzi and Spano. This is an open-access article distributed under the terms of the Creative Commons Attribution Non Commercial License, which permits use, distribution, and reproduction in other forums, provided the original authors and source are credited.