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Craft Beer Sector: New Technologies and Economic Opportunities for Local Development

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Abstract

In recent years, craft beer found an increasing favour among consumers also in Italy that is characterised by no traditions in the production of malts, hops and beer-making, nevertheless the beer market showed a degree of product differentiation never shown before. The aim of this PhD thesis was to investigate with multidisciplinary approach, some key traits related to the emerging Italian craft beer sector. In particular, the thesis investigated if it is possible and profitable to increase the product diversification in craft brewing through the valorization of local raw materials in southern Italy. In this regard, to illustrate the organisational models that characterise the craft beer producers and the incidence of local raw materials on their production, a *face-to-face* analysis to the producers operating in Sicily was carried out in this work. The sector was highly dynamic even if it is substantially linked to extra-regional raw materials; in this context craft producers could give a strong added value and a local character to their production in different ways. Given the importance of the cereal production in Sicily, one of these could be the use of malt derived from small batches of local cereals and/or pseudo cereals. To assess the malting profitability a Cost-Benefit Analysis was carried out for a micro malthouse, considering installation and operating costs of two different processing plants. To test the stability of the Cost-Benefit Analysis results, a sensitivity analysis was performed by varying on one side the malt sales price and on the other side the costs of the required raw materials. Furthermore, investigations were carried out to evaluate the malting performances of different durum wheat landraces (*Triticum turgidum* L. subsp. *Durum,* Desf.). The malting suitability of *Simeto* durum wheat was studied evaluating the effect of two different final drying temperatures on the main enzyme activities and on the malt quality parameters. Moreover, the wort characteristics of the *Simeto* wheat malts employed in combination with commercial barley malt were evaluated under EBC congress mash conditions. Considering the growing interest to investigate wheats with low protein and viscosity, sixteen old durum wheat landraces were malted following the same malting regime, using a common wheat as a control test. The malting quality parameters, the protein and starch degradation processes, the activity of starch-and non-starch polysaccharides-degrading enzymes were studied for the first time on old durum wheat landraces. Considering the effects of non-starch polysaccharides on wort viscosity, arabinoxylans and β-glucans level were measured for wheat grains and for their malts and worts. The results of this thesis show the potential feasibility and profitability of the production of local raw materials for brewing. In particular, the production of malt from local cereals, such as durum wheat, could increase the product diversification and the results of the experimental trials showed suitable characteristics for brewing purposes.

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General introduction

1.1 Socio-economic scenario

Over the last three decades, the consumer's demand for local agro-food products has grown exponentially in United States (US) of America and many European countries (Pratt, 2007; Schifani et al., 2016). Several forces were driving this trend defined as "*neolocalism*", such as the changes in the consumers' preferences, the growing distance between consumers and the standardized mass-products, as well as the interest to renew the connection with local communities and economies supporting the local firms (Flack, 1997). This phenomenon was observed and studied for a wide range of local agro-food products, such as meat, fish, cheese, vegetables, honey as well as beer (Grasseni, 2003; Schnell, 2003; Antonelli et al., 2009; Lanfranchi et al., 2014; Migliore et al., 2015a; Schifani et al., 2016).

The consumers' preferences for alcoholic beverages showed major change during the past 50 years (Nelson, 2005; Polemans and Swinnen, 2011). In particular, the sharing of beer on global alcohol consumption has increased, while the wine consumption declined (Colen and, 2016). Taking a more in-depth look at the traditional beer and wine drinking countries, two different trends were reported. While for United Kingdom (UK), Germany and Belgium, beer consumption decreased and wine consumption increased, the opposite trend was observed for traditional wine drinking countries such as France, Spain and Italy (Colen and Swinnen, 2016). Also, over the last few years, even the production and the market dynamics of the beer sector showed significant changes. In 2003, the global beer production account for 1,173.0 million of hectoliters (mln hl) with the top 4 brewing groups (Anheuser-Busch, SAB-Miller, Heineken and Interbrew) showing the 22.2% of the market share (Meier, 2016). In later years, the beer market was characterized by progressive mergers and acquisitions among competitors: in 2016, the global beer production was about 1,958.0 mln hl with the top 4 groups (AB Inbev, Heineken, China Res. Snow Breweries and Carlsberg) showing 44.5% of the market share (Meier, 2016). From the consumers' point of view, mergers and acquisition among competitors create the possibility to buy the same beer at a lower price due to a reduction of the production costs for the brewers. How reported by Ashenfelter et al. (2015), the reduction of the beer price does not always occur after a merger, and in the US beer market a price increase of about 2% was registered after the merger of the brewers Miller and Coors. The market concentration, usually linked to mature industries, creates favorable conditions for small firms, organized with different business models, to penetrate the market (Carrol, 1985; Carrol and Swaminathan, 1992, 1993, 2000; Swaminathan, 1998). The increasing number of small firms derives also from consumers' growing desire to renew connections with local economies and communities, also rediscovering local traditional food (Pratt, 2007), stimulating the supply of typical products, and thus supporting the existent productive firms (Migliore et al., 2015a; Giannetto et al., 2016). An increasing number of consumers were looking to differentiated local products with high-quality features and unique characteristics. Furthermore, consumers perceive local products as less processed, more natural and usually were considered of higher quality than industrial ones (Migliore et al., 2015b). Following this trend, also the beer consumers were asking for specialty beers produced by local craft brewers according to traditional methods using natural ingredients and showing high economic value (Carroll and Swaminthan, 2000). Moreover, it has been reported that breweries have contributed to the creation of a bond to local communities through product names, visual marketing in labels, social and sustainable business policies (Holtkamp et al., 2016; Feeney, 2017).

The craft brewers have been showing a steady positive trend in many countries with brewing tradition, as well as in other countries, such as Italy, where microbreweries represent a new emerging segment of the agro-food sector. The first craft brewers appear in Italy during 1996, following some legislative innovations, concerning simplification in the assessment of the excise duties, which promoted the development of small breweries. Currently, the Italian craft beer sector consists mainly of three business models differing in ownership of processing plants and product distribution. The "craft brewery or microbrewery" is a small independent brewery, which brews craft beer in its own processing plant, sells its products mainly outside of the brewery, and serves craft beer directly to consumers as a marginal activity. The "brewpub" is a small independent brewery, which brews craft beer in its own processing plant, and sells mainly by serving craft beers directly at the brewery, which acts as a pub. The "beer firm" does not have its own processing plant, and sells craft beer brewed from third parties. The growth of the Italian craft beer sector was exponential over the last few years when the number of craft beer producers increased from 336 units in 2011 to 674 in 2015 (Assobirra, 2016). The Italian craft beer sector shows a high number of brewers and a high degree of product diversification. According to some authors (Fastigi et al., 2015; Esposti et al., 2016), when considering the lack of tradition in beer-making, the spread of Italian craft brewers would not seem to depend on geographical and local factors. Furthermore, in Italy also the production of raw materials suitable for beer, such as malts and hops, has no tradition. Their productions are made in Italy, but starting from foreign raw materials, which have no local character. In some cases, the Italian brewers use local special ingredients in their beers, such as fruits (cherries, peaches, grapes, and chestnuts), herbs and spices (Savastano, 2011). In this regard, the *Italian grape ale*, recognized by the Beer Judge Certification Programs as the first Italian-style beer in 2015 (BJCP, 2016), is brewed using a blend of wort and grape, grape must or sapa (concentrated grape must). Taking into account that from a legal point of view beer must be prepared using barley or wheat malts (also roasted), or their mixtures and water, made bitter by hop and/or his derivatives (article 1 of the Law No. 1354 of 16 August 1962), the special ingredients are used in a limited amount on the beer recipe. In Italy, the craft beer production has been regulated in 2016, when the Government fills the regulatory gap in the identification both of craft beer characteristics and of allowed productive processes (Law No.154, 28 July 2016). Craft beer was defined as the unfiltered, unpasteurized beer produced by small breweries legally and economically independent from any other brewery, using their own processing plants for a maximum annual production volume of 200,000 hectoliters. By the Ministerial Decree No. 212/2010, malt and beer are considered as goods, which are directly or indirectly related to agricultural production. Malting and brewing become agricultural activities when processing at least 51% of raw material produced in the farm, leading to a streamlined taxation regime and the possibility to access the European Union (EU) funding sources from the Rural Development Programme (RDP).

1.2 Technological framework and wheat malt state of art

The US craft beer industry, characterized by greater product differentiation requiring a wider variety of malts, is a source of inspiration for many European craft brewers, leading to a renaissance of micro-malting industry (about 26 micro malthouses in 2014) (Shepherd and Berning, 2015). In Italy, the number of breweries and micro-breweries has grown exponentially to the interest in beer production with unusual cereals and pseudo cereals (Mayer et al., 2011; Di Ghionno et al., 2017). In this regard, the Italian malt productions come from two industrial malting plants (Agroalimentare sud, Melfi, PZ; Malteria Saplo, Pomezia, RM) which purchase and process barley from Italian farms and their production is absorbed, almost entirely, by industrial breweries. Few other micro malt houses appeared in Italy, probably due to the large investment in processing plants and to the lack of technological skills and maltsters. The presence of micro malt houses, by leading to an increase in the demand for malt, might further stimulate the growth of a local craft beer supply chain and help the development of the existent areas under cereal cultivation. The most represented cereal crop of the Mediterranean regions is durum wheat (*Triticum turgidum L.* subsp. *Durum Desf.*), commonly used for pasta and bread making. In 2016, over 2.7 million hectares were cultivated with durum wheat in the EU-28, and the production accounted for about 9.5 million of tons (Eurostat, 2016). Italy represents the principal EU producer with more than 5.0 million of tons of durum wheat harvested in 2016 (Eurostat, 2016; Istat, 2016). In the same year, Apulia and Sicily were the leader regions producing together over the 40% of the national production (Istat, 2016). During the 20th century, the durum wheat breeding programs aimed to the improvement of the agronomic performances and the technological quality. New durum wheat landraces with improved gluten quality led to better technological performance but also higher allergenic potential (De Santis et al., 2017). The local traditional durum wheat landraces, well adapted to the specific environment but less suitable for industrial purposes, have been gradually replaced by high yielding varieties leading to a strong reduction of the biodiversity. The old durum wheat showed wide adaptability and rusticity, which are useful characteristics for the cultivation in the internal and rural areas with reduced rainfall as in the southern Mediterranean regions. The recent EU agricultural policy, promoting the improvement of soil and the low inputs agronomic management, was a driving force for the reintroduction of the wheat landraces in marginal and rural areas enhancing biodiversity. Common wheat (*Triticum aestivum L.)* was, and still is, used in northern Europe as a source of fermentable extract for beer production and malting, and brewing processes have been extensively studied by several researchers (Faltermaier et al., 2014, 2015; Wu et al., 2015). However, few researchers have studied durum wheat malting and brewing processes (Suhasini et al., 2004; Mascia et al., 2016). In a recent review of the use of common wheat as a brewing cereal, Faltermaier and other authors (2014) pointed out the increasing interest to screen wheat landraces for malting and brewing purposes, taking into account that lower protein and viscosity values are suitable characteristics. In the malting process, the hydrolysis of the cereal endosperm occurs by specific enzymes, degrading proteins, starch and non-starch polysaccharides (NSPs). Proteins play an important role in malting wheat affecting yeast nutrition, fermentation, foam stability, beer taste and the recommended values ranged from 11 to 13% of dry matter (Faltermaier et al., 2014). During the malting process, insoluble storage proteins are hydrolysed and further degraded by proteolytic enzymes to polypeptides and amino acids. The endopeptidases cut proteins into lower molecular weight polypeptides further degraded by the exopeptidases into amino acids. High nitrogen levels in malt are inversed related to extract and soluble proteins, but good malt characteristics can also be obtained facilitating the protein degradation by extending the germination phase (Jin et al., 2014). The protein degradation degree (Kolbach index), calculated as the ratio between soluble and total nitrogen, is normally taken into account to monitoring the germination process and the kernel degradation. High Kolbach index values are an indication of extensive protein degradation and result in high respiration rates that cause increasing malting loss (Jin et al., 2012). Different authors reported on the behaviour of foam stability in relationship to protein degradation and in particular low protein degradation lead to a better foam quality and a low foam stability with high Kolbach Index (Evans et al., 1999, 2002). Furthermore, the protein degradation affects the availability and the activities of the polysaccharide-degrading enzyme and the wort quality attributes (Jin et al., 2014). Taking into account that the extract yield represents a key indicator in brewing, relatively low protein values and high starch content were the required characteristics for wheat landraces suitable for malting (Jin et al., 2011). Starch is the most abundant wheat carbohydrate composed of amylose and amylopectin, found as granules within the cells of the endosperm (Faltermeier et al., 2014). A starch content of about 50-75% is recommended for malting wheat (Jin et al., 2011). The starch hydrolysis during germination and mashing produces fermentable sugars and dextrin, which are the main components that constitute the extract of the wort (MacGregor et al., 2002). Several studies on malting cereals found that malt quality parameters, especially the extract yield, depend on starch content (Chandra et al., 1999, Edney et al., 2004, Jin et al., 2011). With regard to NSPs, the wheat genotypes and the grain tissues influence their amount and structure. Beta-glucans in wheat are less represented than in other cereals and concentrated in the aleuronic layer. Their structure consisting mainly of trisaccharide units with more regular structure than beta-glucans from other cereals and this fact makes it less water soluble (Cui et al., 2000). In wheat, arabinoxylans account more than 66% of the endosperm cell wall and can reach about 7% of the whole kernel weight (Faltermaier et al., 2014). The structure of the wheat arabinoxylans consists of a linear backbone of β-D-xylopyranose and α-L-arabinofuranose side-chain at O-3 or both at O-2 and O-3 on the xylose backbone. The arabinose to xylose ratio is an important parameter indicating the degree of substitution of the arabinose residues on the xylan backbone. The arabinoxylan polymerization degree affects their physicochemical properties such as solubility and viscosity (Krahl et al., 2009). In brewing process, high-molecular-weight NSPs may cause reduced extraction efficiency, high viscosity, poor filterability and haze formation in worts and beers (Debyser et al., 1997, 1998, Faltermeier et al., 2015). The high molecular weight 1-3, 1-4-β-D-glucans are solubilised from the cell walls and degraded by endo-β-glucanases such as endo-1,3-β-glucanase, endo-1,3:1,4-β-glucanase and endo-1,4-β-glucanase, during malting and brewing processes. The molecular weight reduction of the β-glucan polymers impact on the wort viscosity by decreasing the average level (Debyser et al., 1998). Low values of endo-β-glucanase activity (3 U g^{-1}) was found in not germinated common wheat (Jin et al., 2014). These endo-enzymes were inactivated after 15 minutes at 50°C, whilst the β-glucan solubilises were still active above this temperature. The high molecular weight β-glucan released during the last part of mashing are no longer degraded (Bamforth et al., 1981, Jin et al., 2004). Because of their high arabinoxylan content the problems related to the extraction efficiency, high viscosity, poor filterability and haze formation were marked when wheat or wheat malt were used as adjunct (Lu et al., 2006). During malting and mashing, several enzymes are involved in arabinoxylans degradation such as endo-1,4-β-D-xylanase, β-D-xylosidase and α-L-arabinofuranosidase. Under the action of the endo-1,4-β-D-xylanases, high molecular weight arabinoxylans are degraded into xylo-oligosaccharides further degraded by β-D-xylosidases releasing xylose monomers and α-L arabinofuranosisases acts to remove arabinose residues from the xylan backbone. The endo-xylanase activity observed in malts and the arabinoxylan concentration in the resulting worts were found to be positively related (Debyser et al., 1997). The depolymerisation operated by endo-1,4-β-D-xylanase affect the physiochemical properties of arabinoxylans such as solubility and viscosity (Krahl et al., 2009, Dornez et al., 2009). The enzymes involved in hydrolysis and degradation of arabinoxylans are produced at the end of the germination process (Banik et al., 1997). The endoxylanase activity detected after 72 hrs of germination was two-time higher than in finished malt (Li et al., 2004). The arabinoxylans hydrolysis from the endosperm cell walls increase the availability of the starch facilitating amylase activities. Different hydrolyzing enzymes attack starch granules producing fermentable sugars and dextrins. The starch degrading enzymes such as β- and α-amylases as well as limit dextrinase, maltase and saccharase, were released and synthesised during the malting process. The malt amylases play a key role in mashing. The β-amylase cuts alternate α-1,4 linkages from the non-reducing end of the starch molecule. This enzyme is present in free, insoluble and latent form in unmalted grains (Evans et al., 1997). The insoluble and latent forms of β-amylases, bound via disulphide bridges to protein compounds, are released during the germination (Faltermaier et al., 2014). Differently from the β-amylase, α-amylase is synthesized in the aleurone cells during the germination process (Faltermaier et al., 2014). The α-amylase cuts the α-1,4 linkages from the inside, degrading amylose and amylopectin to dextrins. It is know that in large-sized corns the release and synthesis of the enzymes occur with slow rate according to the longer time required for germination (Briggs et al., 1998). Common wheat varieties produced in the traditional beer making countries were widely investigated during malting and brewing processes. How previous mentioned, durum wheat is produced in the southern Mediterranean regions, such as Italy, where the craft beer production showed an exponential growth during the last decade. Few studies were carried out about the socio-structural and productive traits of the companies operating in the Italian craft brewing sector. Furthermore, no relevant data are available on the investment profitability in malting local cereals, as none of the published articles investigated the suitability of the traditional durum wheat landraces to malting and brewing purposes.

1.3 Aims, experimental design and content of the study

Based on the above considerations, this thesis assess the feasibility and the profitability to increase the product diversification in craft brewing through the valorization of local raw materials, such as durum wheat, in southern Italy. This thesis investigated with a multidisciplinary approach economic and technologic traits related to the emerging Italian craft beer sector. In particular, the productive characteristics and the critical issues of the local craft brewers were studied, as well as the malting profitability in the Sicilian area. Furthermore, investigations were carried out to evaluate the malting suitability of different durum wheat landraces (*Triticum turgidum* L. subsp. *Durum,* Desf.).

The PhD thesis was organized into six chapters.

Chapter 1 provided the general introduction starting from the overview of the current trend in the beer production and consumption, the main information about the Italian craft beer sector, then focusing on the recent developments and investigations regarding the wheat malt quality.

The following chapters, respectively chapter 2, 3, 4 and 5 present four studies carried out, which constituted original research papers submitted, under review or accepted in international peer-reviewed journals.

Chapter 2 investigated the socio-structural, productive and economic-commercial characteristics of the Sicilian craft brewers through a “*face to face”* survey.

Chapter 3 examined the investment profitability in malting through a cost-benefit analysis considering two different production devices.

Chapter 4 assessed the malting suitability of *Simeto* durum wheat using various process conditions and the durum wheat malt mashing performances in combination with commercial barley malt. Chapter 5 investigated the malting and brewing behavior of 16 durum wheat landraces (*Bidì, Capeiti, Chiattulidda, Farro Lungo, Francesa, Gioia, Giustalisa, Inglesa, Martinella, Realforte, Regina, Russello, Trentino, Tripolino, Tumminia e Urria*).

In chapter 6, some consideration regarding the obtained findings and the further studies in these research fields close the PhD thesis.

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Chapter 2

Microbreweries, brewpubs and beerfirm: characteristics and critical issues of the Sicilian craft beer producers

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Abstract

In recent years, global changes in beer consumption and strong market concentration have contributed to the growth of local craft beer producers. Craft breweries found the favour among consumers also in many European countries, as among which Italy, which is characterised by no traditions in the production of malts, hops and beer-making. This manuscript aims to illustrate, through a descriptive approach, the organisational models that characterise the local craft beer producers and the incidence of local raw materials on their production. To reach this goal we carried out an explorative analysis of the whole universe of craft breweries operating in Sicily. The results of the analysis show a sector characterised by a substantial dependence on the import of malts hops and yeasts and the use of local ingredients is not so widespread among brewers. In our case study, the characteristics of the processing plants and the sales channels appear to influence the diversification of the products and the revenue levels of the Sicilian craft beer producers.

Keywords:

Craft brewing, local craft beer, local raw materials, brewery, brewpub, beerfirm

2.1 Introduction

In the second half of the 20th century, the consumption of mass-produced beer gradually collapsed in the European countries with a strong brewing tradition, although a small reverse trend was reported for other countries, where beer had a marginal role in the beverage industry (Colen and Swinnen, 2016). Following the phenomenon called “taste revolution” (Kleban and Nickerson, 2012) started in the United States (US) during the 1970s, an increasing number of small craft-beer producers gained the favour among consumers, also in Europe (Warner, 2010). The craft-brewed beers do not represent a novelty for the historic brewing countries, such as Germany, Belgium, United Kingdom and Czech Republic. Differently, for other countries such as Italy, where mass-produced beer represented a marginal share of the beverage industries, and few multinational corporations dominate the beer market, craft brewing represents a new fast growing trend (Garavaglia, 2010). This latter creates favourable conditions for small breweries, which are organized with different business models (Carrol, 1985; Carrol and Swaminathan, 1992, 1993, 2000; Swaminathan, 1998, Fastigi et al., 2015, Garavaglia, 2015). The first craft brewers appeared in Italy during 1996, after the issuing of some legislative innovations, concerning simplification in the assessment of the excise duties, which encouraged the development of small breweries (Garavaglia, 2015). From the second part of the 1990s, the Italian craft beer (CB) sector has exponentially grown in number of breweries and average production volume. In particular, the number of CB producers increased from 336 units in 2011 (estimated total production 138,000 hl) to 674 in 2015 (estimated total production 419,000 hl). In the meanwhile, the average production per brewery grows from 411 hectoliters in 2011 to 622 hectoliters in 2015 (Cannatelli and Pedrini, 2012; Ravelli and Pedrini, 2016; Assobirra, 2016).

In Italy, the CB production has been regulated in 2016, when the Government fills the regulatory gap in the identification of CB characteristics and processes permitted in production (Law no. 154, 28 July 2016). CB was defined as the unfiltered, unpasteurized beer, produced by small breweries legally and economically independent from any other brewery, using their own processing plants for a maximum annual production volume of 200,000 hectolitres. The annual production limit includes the beer contract-brewed for third parties. The Italian CB sector consists mainly of three business models: craft brewery or microbrewery, brewpub and beerfirm; differing in ownership of processing plants and product distribution. The “craft brewery or microbrewery” and the “brewpub”, brew CB in their own processing plant. Relatively to their business relationship, the Microbrewery sells its products mainly outside of the brewery, serving CB directly to consumers as a marginal activity, while the brewpub sells mainly by serving CB directly at the brewery, which acts also as a pub. The “beerfirm” does not have its own processing plant and, as a beer retailer, sells CB brewed from third parties.

In accordance with the Italian Ministerial Decree no. 212/2010, malt and beer are considered as goods, which are directly or indirectly related to agricultural production (agricultural beer). Malting and brewing become agricultural activities when processing at least 51% of raw material produced in the farm, leading to a streamlined taxation regime and the possibility to access to European Union (EU) funding sources from the Rural Development Programme (RDP). The malt production gives the opportunity for the craft breweries to increase the degree of product diversification by malting local cereals. Differently to the US beer market, where the high number of craft brewers derives also from consumers’ growing desire to renew connections with local economies and communities, supporting the existent producers which promote local traditional products (Schnell, 2011), Italy has no tradition in the production of raw materials and beer-making. The most part of the Italian CBs are made in Italy, brewing foreign raw materials, which have no local character, therefore the spread of Italian craft brewers would not seem to depend on geographical and local factors (Fastigi et al., 2015; Esposti et al., 2016). In some cases the Italian brewers use local special ingredients in their beers, such as fruits (cherries, peaches, grapes and chestnuts), herbs and spices (Savastano, 2011). In this regard, the *Italian grape ale*, recognized by the Beer Judge Certification Programs as the first Italian-style beer, is brewed using a blend of wort and grape, grape must or sapa (concentrated grape must). From a legal point of view, beer must be prepared using barley or wheat malts (also roasted), or their mixtures, and water bittered by hop and/or his derivatives (article 1 of the Law no. 1354 of 16 August 1962); the special ingredients are used in a limited amount on the beer recipe.

Several authors have investigated the evolutionary dynamics of the Italian CB production and consumption, showing differences in terms of company structure, productive and commercial strategies, and consumers profiles (Fastigi et al., 2015), as well as modelling the entry/exit dynamics in the Italian CB market (Esposti et. al., 2016). No relevant data were found in the literature about the organizational models that characterize the craft breweries, such as the production plants, the types and origins of the raw materials, as well as the beer styles attributes. To bridge this gap, the paper aimed to understand, through an explorative approach, the main organizational models characterising the craft brewing. To reach this goal, a survey was carried out by administering a face-to-face questionnaire. Considering that no relevant data are available in the literature on Sicily (Southern Italy), the focus of our study were 41 craft breweries active this area in 2016.

The paper is organized into six sections. The following section illustrates the survey instrument and the methodology adopted. Section 3 describes the socio-structural and productive features of the surveyed companies. Section 4 focuses on the main types of the raw materials used in the craft brewing process, their origin and supply channels. Section 5 investigates the choices for the packaging, the target markets and the main distribution channels of the Sicilian CBs. Finally, section 6 describes the beers characteristics, the productive capacity, the revenue levels and the groups of CB producers (microbreweries and brewpubs) showing similar structural, productive and economic characteristics. Some considerations close the paper.

2.2 Material and methods

In order to understand the main characteristics of craft breweries and their organizational model, a survey was carried out to 41 craft breweries active in Sicily (Southern Italy) in 2016. They represent the whole universe of craft breweries operating in Sicily, where in the last few years the phenomenon of craft breweries has experienced an important growth. To obtain information as detailed as possible, the data were directly collected by means of a questionnaire specifically designed for the CB sector and adapted from the survey instrument used in previous researches carried out in the agricultural sectors (Schimmenti et. al., 2011, 2013, 2014, 2016; Borsellino et al., 2016). The final version of the questionnaire was previously tested for each of the three business models and then revised following the suggestion of opinion leaders (agribusiness professionals, local academics, etc.). The questionnaire, consisting of closed-ended questions, was submitted during the period between January and August 2017 and the collected data are referred to the year 2016. The survey was carried out through face-to-face interviews with production and sales managers. The questionnaire was organized into four main sections. In the first section, information were collected about the socio-structural features of the company (name, founding year, number of founders, business model, entity of the workforce, consulted external professionals and public funding received) and the production plant characteristics (production area, brewhouse size, amount and volume of fermenters, amount and volume of cold and warm storage rooms, bottling and labelling lines, productive capacity). The second section was functional to gain information about raw materials, such as water (source, frequency of analysis, treatment for pH modification) sources of fermentable extract (types of barley base malt, malts other than barley and unmalted local cereals, country of origin, supply channels), hops (shares of European, US and New World hop varieties used, supply channels), special ingredients (types of ingredients, use of technological adjuvants) and yeasts (yeast strain, supply channels). The third section concerned the productive aspects of surveyed companies, such as annual production volume, number, types, alcohol content and average prices of the brewed beers, packaging types, shares per batch of production. The last section was designed to gather information about the commercial features (target markets, distribution channels, main customer types), the revenue levels (revenue in 2016 and share from direct serving) and the excise duties (excise assessment, share of the taxed product lost as waste during the brewing process).

Finally, a hierarchical cluster analysis was carried out to group companies showing similar structural, productive and economic features. The cluster analysis was performed for the surveyed companies equipped with brewing plants, using the available fermentation volume (continuous), the share of beer direct served (continuous), the number of brewed beers (continuous) and the revenue levels (categorical) as variables. The statistical analysis was carried out by using MATLAB software (MathWorks, version 8.5.0).

2.3 Results

The Sicilian CB sector is composed of companies operating in 8 of the 9 Sicilian provinces, respectively 17 microbreweries, 4 brewpubs and 8 beerfirm in 2016 (Table 1). 70.7% of the company operating in Sicily response to the survey questionnaire; the sample is representative of the 8 Sicilian provinces in which are present operators of the CB sector. The surveyed microbreweries were founded between the 2004 and 2016, the number of founders ranged from a minimum of 1 to a maximum of 12 people, while only 1 company produces agricultural beer (Ministerial decree no. 212/2010). Also the brewpubs were founded during the period 2004-2016; in this case the number of founders ranged between 2 and 3 founders and none of them produces agricultural beer. The beerfirm represented a new trend of the CB sector, the companies involved in this survey were founded between 2014 and 2016 by a maximum of 2 founders and one of the surveyed companies produces agricultural beer.

Productive and socio-structural features

The structural characteristics of the buildings and the production plants of the companies were collected for the companies equipped with the processing plant and therefore no data are available for the beerfirms. The overall brewing area for the breweries was about 3,945.0 m^2 (ranging from a minimum of 70.0 m^2 and a maximum of 450.0 m^2) with an average surface of about 232.1 m^2 per brewery. The brewpubs showed an overall brewing area of 535.0 m^2 (ranging from a minimum of 65.0 m^2 and a maximum of 200.0 m^2) and the average surface dedicated to the brewing activity was about 133.8 m^2. The average volume of the “brewhouses” was 6.0 hl for the breweries (overall volume of 102.0 hl, ranging from 1.0 hl to 16.0 hl), while for the brewpubs was 4.0 hl (overall volume 16.0 hl, ranging from 3.0 hl to 5.0 hl). The surveyed companies carry out the wort fermentations on a total of 82 fermentation tanks, respectively 71 for the microbreweries and 11 for the brewpubs. The average fermentation volume available for each production plant was 43.4 hl for the microbreweries and 32.9 hl for the brewpubs. Taking into account that the maturation tanks were detected only in few production plants, the average volume was 5.6 hl for the microbreweries and 7.5 hl for the brewpubs. In this regard, it is important to note that the variability observed for the brewing surface, brewhouse size, number and volume of the fermentation tanks, is due to the different production policies adopted by the brewers. In particular, the brewpubs show a smaller size of the production plants with the exception of the average maturation volume. This fact is due to the possibility for the brewpubs to serve by tapping beers directly from the maturation tanks. On the other side, the production plants of the microbreweries were all equipped with the bottling lines with an average bottling capacity of 185.3 l h^{-1} and including, in some cases, worm rooms (average volume of 43 m^3) to bottles conditioning. Compared to microbreweries, the brewpubs equipped with bottling lines show a lower bottling capacity (70.0 l h^{-1}) and a reduced volume dedicated to bottle conditioning (5 m^3). Conventionally, the storage of the conditioned bottles is carried out at low temperature in cold rooms. The surveyed companies were not all equipped for the storage of the conditioned bottles, and on average the microbreweries show a lower volume (27.9 m^3) of the cold rooms compared to brewpubs (33.8 m^3). Probably these differences are due to the high incidence of the brewing plants (brewhouse, bottling lines, fermentation and maturation tanks) on the total brewing area of the microbreweries and also for the high demands in cold storage required by brewpubs for products other than beers.

Some of the surveyed companies during the construction phases have benefited from public funding from the Italian Ministry of Economy and Finance, to promote private investment and boost economic growth revitalizing crisis areas such as Sicily. In particular, the 58.8% of the microbreweries received on average 82,700 € (from a minimum of 5,000 € to a maximum of

150,000 €) for the structural adjustment of the brewery buildings and the acquisition of brewing plants. The public funding is of particular importance to support strategic sectors for development and employment, especially for the southern Italian regions. The workforce of the surveyed companies of the Sicilian CB sector consists of 73 workers of which 65 have a permanent position. The most part of the workforce is concentrated in the microbreweries (52 units), followed by the beerfirms (13) and the brewpubs (8). The workforce consists of three key figures, respectively managers, employees and seasonal workers, all resident in the municipalities near the companies' production plants or registered offices. The managers account for 63.5% of the total number workers employed in the microbreweries, while the share rise to 75.0% and 92.3%, respectively for the brewpubs and the beerfirms. The employees and the seasonal workers account for 36.5% on the total workforce of the microbreweries, while for brewpubs and beerfirms the shares decrease respectively to 25.0% and 7.7%. No seasonal workers were involved in the activity of the surveyed beerfirms. In this regard, the average amount of workers per company ranged from 3.06 to 1.63, respectively for the microbreweries and the beerfirms, due to the reduced labour required to brew for brewpubs and beerfirms.

Several external professionals are involved in the activities of the Sicilian CB sector, such as lawyers, accountants, food technologists and marketing expert. In 2016, the microbreweries resorted on average to 2.24 external consultants, mainly represented by professionals, such as accountant (42.1%), marketing experts (18.4%) and food technologists (15.8%). The number of external professionals required by the brewpubs was on average 2.50, mainly represented by accountants (40.0%), food technologist (30.0%) and marketing experts (20.0%). The activity carried out by the beerfirms required less external skills, on average 1.52 external professional were consulted among accountants (58.3%) and marketing experts (25.1%). In this regard, it is interesting to note that the shares of the consulted marketing experts were comparable between microbreweries and brewpubs, but it grows significantly for the beerfirms. These larger investments in marketing strategies to promote the beerfirms are probably due to the lack of the own production plant, which leads to a reduced connection with the local communities that normally support the existing producers in the area.

Raw materials and supply channels

In accordance with the article 1 of the Italian Law no. 1354 of 16 August 1962, beer must be prepared mashing barley or wheat malts (also roasted), or their mixtures and water, bittered by hop and/or his derivatives. In beer, water represents the main ingredient in quantitative terms, and the chemical characteristics play a key role in the process efficiency and for the taste perception of malts and hops. Sicilian brewers use water from the municipal water network to prepare their beers. The interviewed companies every six months send to laboratories the water samples to have a complete overview of the chemical composition of their brewing water. 41.2% of the microbreweries carry out a reverse osmosis treatment of the water, because of the high concentrations of some mineral salts that can affect the brewing processes. The water reverse osmosis treatment is not carried out in the case of the brewpubs because, according to the opinion of the brewers, the overall water quality is sufficient for brewing purposes. 47.1% of the microbreweries and 50.0% of the brewpubs correct the water pH, lowering the average level by adding salts (calcium sulphates, magnesium sulphates etc.) or acids (lactic acid, citric acid etc.) to promote an optimal activity of the enzymes in mashing.

With regard to the barley base malts, table 2 shows the main information about the malt type, the supply channels and the country of origin. Pilsner-type barley malt is the most used base malt among the surveyed companies, and the pale ale-type barley malt is used by 11.8% of the microbreweries and 37.5% of the beerfirms. The most part of the surveyed companies purchases base malt from Italian retailers of international brands, while one microbrewery and one beerfirm, producing agricultural beer, process their barley previously malted by Italian maltsters. The German brands represent the most popular malts used by the surveyed companies, respectively 58.8% of the microbreweries, 75.0% of the brewpubs and 50.0% of the beerfirms. The surveyed companies use a relevant share of Belgian malts and except for the brewpubs also UK malt brands. It is interesting to note that only 5.8% of the microbreweries purchase Italian malts, showing that the Sicilian CB sector is heavily dependent on imported malt. Considering the information collected during the survey, there is a general opinion that the Italian malts are expensive and of lower quality than the international ones.

The surveyed companies produced beer also using malt other than barley as listed in table 2. The wheat malt is used for the production of the traditional German wheat beer and to improve the quality of the beer foam of different beer styles. 64.7% of the microbreweries, all the brewpubs and 25.0% of the beerfirms used wheat malt to brew at least one of their beers. The oat malt is used by 11.7% of the microbreweries and 12.5% of the beerfirms, while only 11.7% of the microbreweries use rye malt. The malts other than barley were purchased from Italian retailers of German malt brands for most of the surveyed companies, followed by Belgian, UK and Holland malt brands.

Unmalted cereals represent a source of fermentable extract and are used in small quantities for the production of different beer styles. Wheat is the only unmated cereal used by the surveyed companies and in order to impart a local character to their beers, local wheats are used by the 58.8% of the microbreweries and 12.5% beerfirms at least in one of their productions.

The surveyed companies used European, American and New World (New Zealand and Australian) hop varieties. Considering the lack of Italian hop farmers, all the surveyed companies purchased hops from Italian retailers of international hop brands. The European hops represent the varieties widely used by microbreweries and brewpubs respectively for 55.6% and 51.2% of the total amount of hop used in 2016. For the beerfirms about the 50.0% of the total amount of hops is represented by American varieties, normally used for the production of the popular *India pale ale* beer styles, while for microbreweries and brewpubs these hop varieties were used in a reduced amount. Microbreweries, brewpubs and beerfirms used the so-called New World hop varieties, characterized by tropical and fruity aromatic notes, respectively in the rate of 5.9%, 5.8% and 7.5%. It is worth noting that the beerfirms differentiate their production using higher quantities of American and New World hop varieties to brew full-flavoured ales.

Other special ingredients were used in beer production and are listed in table 3. 76.5% of the microbreweries, 50.0% of the brewpubs and 25.0% of the beerfirms used spices (cardamom, coriander, cinnamon, thyme, anise, pepper, chili pepper, sumac and ginger), flowers other than hop, as well as citrus peel (orange, lemon and mandarin) to give a characteristic spiced aroma at least in one of their beers. 53.8% of the microbreweries and all the beerfirms purchased these aromatic ingredients from local producers, while the brewpubs preferred national supply channels.

Honey was used in 2016 by 35.3% of the microbreweries, 25.0% of the brewpubs and 12.5% of the beerfirms. With regard to the honey supply channels, all the surveyed companies purchased this special ingredient from local producers.

Different fruits, such as oranges, prickly pears, carobs, coconut, mangos, grapes and raisins were used in brewing by 41.2% of the surveyed microbreweries and 37.5% of thee beerfirms. 85.7% of the microbreweries and 66.7% of the beerfirms preferred local supply channels for the fruits used at least in one of their beers.

The Sicilian brewers used international yeast strains (*Saccharomyces cerevisae*) suitable to produce top or bottom fermented beer. The surveyed companies purchased the yeasts from Italian retailers of international brands, with a clear preference for top fermenting dry yeasts made in France, suitable to produce ales. Only two of the surveyed companies, respectively a microbrewery and a brewpub used bottom fermenting dry yeast (France) to produce lager beers. Moreover, the 17.6% of the microbreweries used top fermenting cream yeasts purchased from an Italian producer of international yeast strains.

The results show a substantial dependence on import for malts, hops and yeasts. The unmalted wheat and special ingredients, which account in small quantities on the beer recipe, represent the local raw materials used by the Sicilian brewers.

Packaging, target market and distribution channels

Kegs and bottles represent the most common packaging for CBs. In table 4 are shown the shares of kegs and bottles on total packaging and the related target market.

On average for a batch of beer, the bottles account for 76.5% of the total amount of packaging for the microbreweries, while the share rise to 80.6% for the beerfirms. Kegs on average are used for a lower portion of the batch of beer by microbreweries and beerfirms, while the brewpubs show an opposite trend. In the case of the brewpubs, which sell mainly by serving CBs directly at the brewery, on average the kegs account for 72.5% of the total amount of packaging.

The target market for the surveyed companies is represented by the regional market, both for kegs and bottles. In particular, only a reduced share of the distributed kegs reach other markets within national borders, respectively the 12.1% for the microbreweries and the 12.5% for the beerfirms. Taking into account the bottles market, the interviewed companies on average are able to reach national markets with different shares of the whole bottles distributed. Further marginal shares of the Sicilian CB bottles reach foreign markets, respectively the 4.2% from the microbreweries production and about 0.9% from the beerfirms distribution.

The surveyed microbreweries and beerfirms mainly used disposable kegs, with advantages associated to the low keg weight (empty 20 l container 0.3-1.31 kg) and cost (20 l container 10-18 € keg^{-1}), eliminating recovery and washing phases required for the traditional stainless steel keg. In this regard, traditional stainless steel kegs represent a one-time expensive investment and were preferred by the brewpubs that generally do not distribute their beer.

With regard to the bottles, the surveyed companies used four different sizes 0.33 l, 0.5 l, 0.75 l and 1.5 l. Microbreweries, beerfirms and one of the surveyed brewpubs mainly used the 0.33 l bottle, with a cost comprised in the range 0.20-0.85 € bottle^{-1} (the cost include bottle, label and cap).

The 0.5 l bottle is not very widespread among CB producers and is used by two microbreweries and one brewpub (which uses only one bottle size), with a cost of 0.4-0.5 € bottle^{-1}. The 0.75 l bottle with a cost in the range 0.4-1.4 € bottle^{-1} is used by the 88.2% of the microbreweries, all the beerfirms and one of the brewpubs. 29.4% of the microbreweries sold special productions, such as celebrative and Christmas beers, using the 1.5 l bottle size, with a cost comprised between 2.3 and 4.0 € bottle^{-1}.

The companies involved in the Sicilian CB sector resort to different sales channels, such as direct beer serving (on-site for brewpubs and during fairs and festivals for microbreweries and beerfirms), direct distribution (direct sales), indirect distribution (external distributors) and contract-brewed beer for third parties (beerfirms, pubs, bars and restaurants).

In table 5 is shown how the three business models distribute their products among the different sales channels. For the microbreweries, on average the beer serving in fairs and festivals represents a share of 7.2% of the sales channels, while direct and indirect distribution account respectively for the 48.5% and the 37.2% of the total sales. The beer contract brewed for third parties represents on average the 7.1% of the total sales of the microbreweries.

About the brewpubs, the beer serving on-site represents the main sales channel (72.5%), while the shares of direct and indirect distribution account on average for 7.5% and 17.5% of the total sales. The beer contract-brewed for third parties represents a marginal share (2.5%) of the sales channels for the brewpubs.

The direct distribution represents the main activity of the beerfirms and accounts for a share of 85.6% of the sales channels, while direct beer serving in fairs and festivals and indirect distribution represent the 13.1% and the 1.3% of the total sales respectively.

Taking into account the different incidence of the direct distribution among the sales channels, table 5 shows the main types of customer and the respective shares on the distributed beer volume.

The pubs are an important item among CB customers and on average purchased 26.6% of the beers distributed by microbreweries, 37.5% from brewpubs and 35.0% from beerfirms. The surveyed companies provide to shops dedicated to the exclusive sale of beer, the so-called beershop, about 18.2% of the beer distributed by microbreweries, 10.0% from the brewpub and 23.7% from the beerfirms. The Sicilian brewers distribute in low percentage to wholesale traders, while the sector horeca on average absorb the most part of the beers from microbreweries (43.8%), brewpubs (45.0%) and beerfirms (38.0%).

Beers characteristics, productive capacity and revenue levels

In Sicily during 2016, the surveyed companies produced about 135 different labels, mainly represented by ales, belonging to 29 different beer categories (BJCP beer styles) of the American, Belgian and German tradition (table 6). The microbreweries produced 85 beer labels showing an average alcohol content (ABV) of 6.5% with an average price of 7.0 € l^{-1}. The brewpubs produced 22 beer labels with an average ABV of 5.6% and an average price of 8.9 € l^{-1}. The beerfirms count 28 different labels showing an average ABV of about 6.7% and an average price of 6.3 € l^{-1}. It is interesting to note that beerfirms, although not having production plant, on average show the lowest selling price probably due to the attempt to gain market share at the expense of microbrewers. With regard to the brewpubs, the higher average selling price was probably due to the small size of the production plants that lead to a high incidence of the fixed costs.

The number of beers produced for each category is shown in table 6. The *India Pale Ale* (IPA) represents the widespread beer category with 16 different labels divided between *American* and *specialty* (Belgian, black, brown, red, rye and white) IPAs. The *strong Belgian ales* with 14 different labels were mainly represented by *saison* and *blonde* beer styles. The *German wheat beer* category, counts 12 different labels of *weissbier* and *dunkel weissbier* styles produced brewing at least 50% of wheat malt. The *Italian grape ale*, the *fruit* and s*piced* beer categories, are not so widespread among Sicilian brewers and were mainly produced by microbreweries. In this regard, the Sicilian CB producers add special ingredients also to beer style that normally do not require the use of spices, honey or fruits.

The 64.7% of the surveyed microbreweries produced less than 500 hl, while the 29.4% had a production comprised between 500 and 1,000 hl and only the 5.9% of the sample exceeds 1,000 hl (table 7). The brewpubs showed lower productivity compared to microbreweries, the 75.0% of the sample produced less than 500 hl, and none of them exceeds 1,000 hl. The beer contract-brewed for the 75.0% of the beerfirms was lower than 250 hl, and none of the surveyed companies exceeds 500 hl. Taking into account the national production per brewery estimated in 2015, equal to 622 hl

(Ravelli and Pedrini, 2016), the Sicilian CB producers show a lower productivity that was comparable to the 2011 national average production of 411 hl (Cannatelli and Pedrini, 2012).

The revenue levels of the surveyed companies in 2016 are shown in table 8. The three business models, characterised by different productivity, show an average revenue level lower than 100,000 € for 41.1% of the microbreweries, 50.0% of the brewpubs and 87.5% of the beerfirms.

The revenue levels detected during this survey were on average slightly higher than the data reported for the Italian CB sector in 2011 by Cannatelli and Pedrini (2012), when most of the microbreweries (57.6%) and brewpubs (61.9%) showed a revenue level lower than 100,000 €. The most part of the surveyed microbreweries show a revenue level over 100,000 €, respectively 41.2% comprised between 100,000 and 200,000 €, 11.8% in the range 200,000-300,000 € and only 5.9% over 300,000 €. With regard to the brewpubs, the remaining 50.0% does not exceed the revenue level of 200,000 €, while 12.5% of the beerfirms show a revenue in the range 200,000-300,000 €.

In Italy, according to the recent legislative updates (Decree-law no. 133/2013), starting from 1st January 2015 the excise duties on beer are equal to 3.02 € per hectolitre per Plato degree, both for small craft producers or industrial one. Furthermore, the Italian excise duties are among the highest in Europe (Assobirra, 2016). The excise duties are calculated for microbreweries based on the total wort volume measured by a litre counter certified by the customs agency. Due to the production losses, such as the yeast and/or hop removal from the fermentation tank, part of the product subject to excise is lost as waste. The 70.6% of the surveyed microbreweries and the 75.0% of the brewpubs declared losses as waste during the production process in the range 6-10%. Considering that in Italy beer represents the only beverage consumed during meals that pays excise duties, this high fiscal load could limit the growth of the micro CB producers. Probably a reduction of the excise duties for the Italian beer sector, with a differentiation of the fiscal regime between industrial and craft producers could promote the growth of the entire beer sector generating more jobs and new business.

Figure 1 shows the dendrogram of the cluster analysis performed using the data available for the companies equipped with brewing plants. The results of the cluster analysis show three groups of companies with similar characteristics in terms of fermentation volume, share of beer direct served, number of brewed beers and revenue levels. The characteristics of the clusters are summarized in table 9. The first cluster consists of two companies characterised by a reduced fermentation volume, selling entirely by serving CBs directly, producing more than 6 different labels with a revenue level in the range 75,000-150,000 €. The companies grouped in this cluster were the brewpubs that sell their beers only on-site, and the reduced availability of fermentation volume allow brewers to test different recipes increasing the product diversification. The second cluster brings together six companies that were characterised by the highest fermentation volume, with a reduced share of beer direct served, producing more than 5 different labels and showing revenue levels comprised between 200,000 and 300,000 €. The third cluster consists of the most of the surveyed companies that show a fermentation volume over 30 hl, with a share of beer direct served comparable to the second cluster, producing more than 4 different labels and characterised by the lower revenue levels. Taking into account that the second and the third cluster show similar characteristics in terms of beer direct served and number of brewed labels, the significant differences found for the revenues levels are probably due to the different fermentation volume that affects the productivity of the companies.

2.4 Conclusions

The results of this survey show that the Sicilian CB sector consists of small enterprises with substantial structural and productive differences. The companies have benefited from public funding for the structural adjustment of the productive buildings and the acquisitions of the processing plants. In comparison to the national average production, the surveyed companies show lower production volume that does not always ensure a reasonable margin of profitability. In this regard, considering the differences observed for the economic performances, the proper choice of the business model, the size and typology of the process plants play a key role during the design phase.

Furter efforts should be made to increase the volume available to the cold beer storage that resuts essential to preserve the organoleptic characteristics of beer with high-quality standards also during the hot summer months.

The CB sector shows a substantial dependence on import for malts hops and yeasts and only a few companies were agricultural beer producers. The unmalted wheat represents the most widespread source of fermentable extract produced at the local level and used by the Sicilian brewers. The use of local special ingredients is not so widespread among Sicilian brewers and occurs in a limited amount on the recipe even to beer styles that normally do not require the use of spices, honey or fruits. This fact led to a strong diversification of the products, the sector shows a relatively high number of labels belonging to 29 different beer categories with a high heterogeneity of prices and alcohol content, and are mainly distributed at the regional level. In this regard, even if the beers show weak local character, the Sicilian consumers absorb the most of the CBs produced in the region, supporting the local brewers with positive implications in terms of development and employment. According to other authors (Fastigi et al., 2015; Esposti et al., 2016), also the spread of the Sicilian craft brewers would not seem to depend on geographical and local factors, considering that the most part of the Sicilian CBs are produced brewing foreign raw materials. It would be interesting to investigate if the presence of a micro malthouse could increase the local character of the CB productions using local cereals for malt production. Furthermore, to overcome the limitation of this explorative analysis, such as the limited geographical area and amount of enterprises, further investigation will be necessary at national level taking into account the regional peculiarities related to the CB production.

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Table 1. Composition of the Sicilian CB sector, companies surveyed and questionnaire response rates.

Item	**Brewery**	**Brewpub**	**Beerfirm**	**Total**
CB sector 2016 (no.)	23	7	11	41
Companies surveyed (no.)	17	4	8	29
Response rate (%)	**73.9**	**57.1**	**72.7**	**70.7**

Source: Author elaboration

Table 2. Main information about the barley base malt, malt other than barley and unmalted cereals brewed in 2016 (%)

Item	Brewery	Brewpub	Beerfirm
-Barley base malt:			
Pilsner	88.2	100	62.5
Pale ale	11.8	0.0	37.5
Total	***100.0***	***100.0***	***100.0***
-Malt supply:			
Foreign malsters	0.0	0.0	0.0
Italian retailers	93.0	100.0	95.0
Italian malsters	7.0	0.0	5.0
Total	***100.0***	***100.0***	***100.0***
-Malt origin country:			
Germany	58.8	75.0	50.0
Belgium	17.6	25.0	25.0
United Kingdom	11.7	0.0	25.0
Holland	6.1	0.0	0.0
Italy	5.8	0.0	0.0
Total	***100.0***	***100.0***	***100.0***
-Malt other than barley:			
Wheat	64.7	100.0	25.0
Oat	11.7	0.0	12.5
Rye	11.7	0.0	0.0
None	11.9	0.0	62.5
Total	***100.0***	***100.0***	***100.0***
-Malt origin country:			
Germany	83.4	75.0	100.0
Belgium	3.3	25.0	0.0
United Kingdom	6.6	0.0	0.0
Holland	6.7	0.0	0.0
Total	***100.0***	***100.0***	***100.0***
-Unmalted local wheat:			
yes	58.8	0.0	12.5
no	41.2	100	87.5
Total	***100.0***	***100.0***	***100.0***

Source: Author elaboration

Table 3. Special ingredients used by CB companies (%)

Items	**Brewery**	**Brewpub**	**Beerfirm**
Spices	76.5	50.0	25.0
of which local product	*53.8*	*0.0*	*100.0*
Honey	35.3	25.0	12.5
of which local product	*100.0*	*100.0*	*100.0*
Fruit	41.2	0.0	37.5
of which local product	*85.7*	*0.0*	*66.7*

Source: Author elaboration

Table 4. Packaging material and market shares (%)

Items	**Brewery**	**Brewpub**	**Beerfirm**
-Packaging:			
Kegs	23.5	72.5	19.4
Bottles	76.5	27.5	80.6
Total	***100.0***	***100.0***	***100.0***
-Kegs market:			
regional	87.9	100.0	87.5
national	12.1	0.0	12.5
foreign	0.0	0.0	0.0
Total	***100.0***	***100.0***	***100.0***
-Bottles market:			
regional	78.2	95.0	85.6
national	17.6	5.0	13.5
foreign	4.2	0.0	0.9
Total	***100.0***	***100.0***	***100.0***

Source: Author elaboration

Table 5. Main beer distribution channels and customer types chosen of the surveyed companies (%)

Items	**Brewery**	**Brewpub**	**Beerfirm**
-Distribution channels:			
Serving	7.2	72.5	13.1
Indirect distribution	37.2	17.5	1.3
Contract brewed	7.1	2.5	0.0
Direct distribution	48.5	7.5	85.6
Total	***100.0***	***100.0***	***100.0***
-Customer types:			
Pub	26.6	37.5	35.0
Beershop	18.2	10.0	23.7
Wholesale trader	11.4	7.5	2.5
Horeca	43.4	45.0	38.8
Other	0.4	0.0	0.0
Total	***100.0***	***100.0***	***100.0***

Source: Author elaboration

Table 6. Beer categories (BJCP), average alcohol content and price of the beers brewed in Sicily

	Brewery			**Brewpub**			**Beerfirm**		
Beer categories	N.	ABV%	Price (€ l^{-1})	N.	ABV%	Price (€ l^{-1})	N.	ABV%	Price (€ l^{-1})
International Pale Lagher	-	-	-	-	-	-	1	5.5	4.5
Czech Pale Lagher	1	5.0	10.0	-	-	-	-	-	-
Pale Malty European Lagher	-	-	-	2	4.8	9.5	-	-	-
Pale Bitter European Lager	2	4.5	4.5	1	5.7	10.0	-	-	-
Amber Malty European Lager	1	7.1	7.0	2	5.6	9.5	-	-	-
Amber Bitter European	1	5.2	5.0	1	5.7	9.0	-	-	-
Dark European Lager	1	5.0	6.6	-	-	-	-	-	-
Strong European Beer	-	-	-	-	-	-	1	9.0	7.0
German Wheat Beer	3	5.3	6.5	6	5.0	9.2	3	5.1	6.7
British Bitter	1	7.0	9.0	-	-	-	-	-	-
Pale Commonwealth Beer	6	5.0	6.3	1	5.0	9.0	3	5.0	6.2
Brown British Beer	3	5.7	6.9	1	5.2	9.0	-	-	-
Irish Beer	4	6.8	7.1	1	5.5	8.0	-	-	-
Dark British Beer	3	5.7	7.0	-	-	-	1	7.8	6.0
Strong British Ale	1	10.4	8.0	-	-	-	-	-	-
Pale American Ale	6	5.2	6.4	1	5.5	8.8	4	5.4	6.1
Amber&Brown American Beer	2	5.3	6.3	1	7.0	9.0	2	6.5	7.8
American Porter And Stout	1	8.0	6.0	-	-	-	-	-	-
India Pale Ale	9	6.0	6.5	2	6.1	9.0	5	7.1	5.6
Strong American Ale	2	9.5	9.8	-	-	-	1	7.0	6.5
Belgian Ale	6	5.3	6.1	-	-	-	1	6.2	7.0
Strong Belgian Ale	12	6.6	6.7	1	5.0	8.0	1	6.3	5.0
Trappist Ale	6	7.5	6.6	1	6.5	9.0	2	7.3	5.3
Fruit Beer	4	6.7	7.3	-	-	-	-	-	-
Spiced Beer	3	6.8	6.0	-	-	-	1	7.0	7.0
Alternative Fermentable Beer	1	6.0	5.0	-	-	-	-	-	-
Smoked Beer	-	-	-	1	5.6	9.0	-	-	-
Specialty Beer	3	7.8	7.0	-	-	-	-	-	-
Italian Grape Ale	3	8.2	10.7	-	-	-	2	8.1	8.0
Amount, average alcohol and price	***85***	***6.5***	***7.0***	***22***	***5.6***	***8.9***	***28***	***6.7***	***6.3***

N.= number of beers; ABV= alcohol by volume; Source: Author elaboration

Table 7. Annual production volume in 2016 (%)

Beer production	Brewery	Brewpub	Beerfirm
≤ 250 hl	35.3	25.0	75.0
> 250 ≤ 500 hl	29.4	50.0	25.0
> 500 ≤ 1,000 hl	29.4	25.0	0.0
> 1,000 ≤ 2,000 hl	5.9	0.0	0.0
> 2,000 hl	0.0	0.0	0.0
Total	***100.0***	***100.0***	***100.0***

Source: Author elaboration

Table 8. Beer revenues for the surveyed breweries, brewpubs and beerfirm in 2016 (%)

Revenue	Brewery	Brewpub	Beerfirm
≤ 25,000 €	11.8	0.0	25.0
> 25,000 ≤ 50,000 €	23.5	25.0	50.0
> 50,000 ≤ 100,000 €	5.8	25.0	12.5
> 100,000 ≤ 200,000 €	41.2	50.0	0.0
> 200,000 ≤ 300,000 €	11.8	0.0	12.5
> 300,000 €	5.9	0.0	0.0
Total	***100.0***	***100.0***	***100.0***

Source: Author elaboration

Table 9. Characteristics of the selected clusters

	Fermentation volume hl	**Beer direct served %**	**Brewed beers (no.)**	**Revenue**
Cluster 1	7.3	100.0	6.5	> 75,000 ≤ 150,000 €
Cluster 2	96.7	10.3	5.2	> 200,000 ≤ 300,000 €
Cluster 3	30.8	11.6	4.8	> 50,000 ≤ 100,000 €

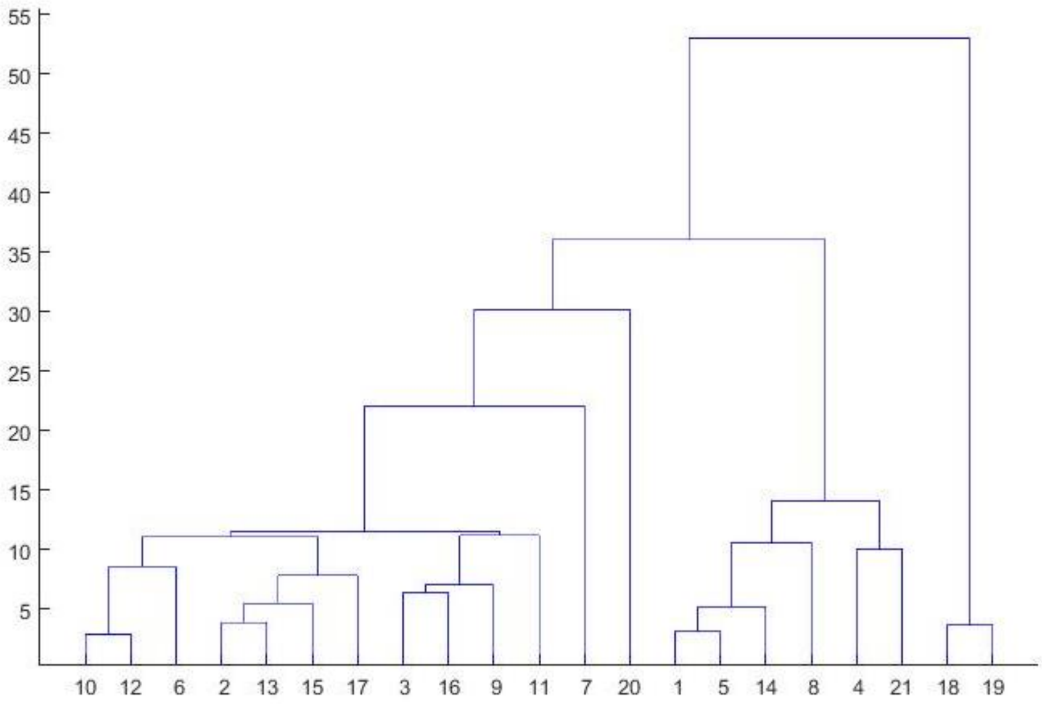

Figure 1. Dendrogram of the hierarchical cluster analysis performed for the breweries and brewpubs (x axis = CB producers; y axis = distances)

APPENDIX

Survey questionnaire

Università degli Studi di Palermo
Dipartimento Scienze Agrarie, Alimentari e Forestali (SAAF)

Dottorato di ricerca in Scienze Agrarie, Forestali e Ambientali
Ciclo XXX
Tutela e valorizzazione delle produzioni agro-alimentari

SCHEDA DI RILEVAZIONE DELLE CARATTERISTICHE STRUTTURALI E TECNICO-ECONOMICHE DELLE IMPRESE DI PRODUZIONE DI BIRRA ARTIGIANALE OPERANTI IN SICILIA NEL 2016

RILEVATORE ……………………………………

1. CARATTERI GENERALI DELL'IMPRESA DI PRODUZIONE DELLA BIRRA

Denominazione dell'impresa
…………………………………………………………………………………….
Ragione Sociale
……………………………………………………………………………………………………

Mese e anno di costituzione dell'impresa
Mese e anno di inizio attività

Sede legale
Via/Piazza (o località)……………………………………………Prov. ………
Comune…………………….
Tel. ……………………………………….. Fax ……………………………………………..

N. Stabilimenti ………….
Stab. 1 Via/Piazza (o località)……………………………………………Prov. ………
Comune……………………. Tel. ………………………………………….. Fax
……………………………………..

Stab. 2 Via/Piazza (o località)……………………………………………Prov. ………
Comune……………………. Tel. ………………………………………….. Fax
……………………………………..

Stab. 3 Via/Piazza (o località)……………………………………………Prov. ………
Comune……………………. Tel. ………………………………………….. Fax
……………………………………..

Associazione di categoria: no ☐ si ☐ (se si, specificare)……………………………………….

Tipo di impresa (**specificare** se produttori di **birra agricola** ai sensi del DM212/2010):

Birrificio Agricolo

- Birrificio (> 200.000 hl/anno)…………………….. ☐ — no ☐ si ☐
- Micro birrificio……………………………… …...☐ — no ☐ si ☐

(< 200.000 hl/anno, piccolo birrificio indipendente DDl 1328-B 2016)

- Brewpub ☐ — no ☐ si ☐

Forma Giuridica:

- Impresa individuale ☐
- Impresa collettiva ☐

Società di persone ☐ Società di capitali ☐ Società Cooperativa ☐ Altro☐

S. a. S. ☐ S. r. l. ☐

S.s. ☐ S. p. a. ☐

S. n. c. ☐

Soc. di fatto ☐ Numero di Soci: ……………………………………

2. PERSONALE

Addetti fissi	**Numero**	**Titolo di studio**
Dirigenti		
Impiegati		
Operai Specializzati		
Operai generici		

Addetti stagionali	**Numero**	**Titolo di studio**
Impiegati Giornate di lavoro complessive n. ……..		
Operai specializzati Giornate di lavoro complessive n. ……..		
Operai generici Giornate di lavoro complessive n. ……..		

Consulenti esterni:
Legale ☐
Commercialista ☐
Tecnologo Alimentare ☐
Esperto di marketing ☐
Altro (Specificare)……………………… ☐
Nessuno ☐

Ha ricevuto finanziamenti per l'attività? ☐ no ☐ si
Se **si** specificare:
In quale anno? ……………………………………………………….
Da parte di chi? ………………………………………………………
Per quale importo? ……………………………………………………
Pensa di usufruire delle opportunità del PSR Sicilia 2014-2020? ☐ si ☐ no
(in caso di risposta affermativa specificare la sottomisura………………………..)

3. CARATTERISTICHE STABILIMENTO

Superficie degli stabilimenti [m^2]: ………
Coperta [m^2]: ……….. Scoperta [m^2]:……….

Capacità di immagazzinamento

Tipologia	Numero	Capacità
Fermentatori		[hl]
Maturatori		[hl]
Cella frigorifera		[m^3]
Camera di rifermentazione		[m^3]

4. IMPIANTI

- **Lavorazione materie prime (sala cottura):**

Alimentazione sala cottura: Gas ☐ Elettrico ☐ Misto ☐

Tipologia	Numero	Capacità
Mulino per malti		[q.li/h]
Addolcitore Acqua		
Caldaia per acqua di processo		[l/ora]
Tino di ammostamento		[hl]
Tino di filtrazione		[hl]
Wirpool (se presente)		[hl]
Pompe volumetriche di mov. liquidi		[l/s]
Altro		

- **Linea di confezionamento:**

Movimentazione birra:
con pompe ☐
in contropressione ☐

Tipologia	Numero	Capacità
Imbottigliatrice		[l/ora]
Etichettatrice		[etichette/min]

5. MATERIE PRIME

- **Acqua**

Provenienza:…………………………………………………………………………………
Pretrattamenti: ☐ no ☐ si (se si specificare)…………………………………………...
Analisi acqua: ☐ no ☐ si (se si specificare la frequenza)……………………………….
Correzione pH per lavaggio trebbie: ☐ no ☐ si (se si specificare metodo):
…………………………………………………………………………………………

- **Malti**
- **Acquisto malti:**
- direttamente da produttori esteri ☐; (% sul totale acquistato)…………………
- da importatori italiani ☐; (% sul totale acquistato)……………………..
- direttamente da produttori italiani ☐; (% sul totale acquistato)………………

Malti di base (indicare quali vengono usati prevalentemente)

Denominazione	**Casa produttrice**	**Paese di provenienza**	**Prezzo €/kg**

Malti Speciali e/o cereali diversi dall’orzo

Denominazione	**Casa produttrice**	**Paese di provenienza**	**Prezzo €/kg**

- **Luppoli**
- **Acquisto Luppoli: Europei ☐; USA ☐; New world ☐ (EU % $_{\text{tot}}$..............; USA%$_{\text{tot}}$………………New world % $_{\text{tot}}$………………)**
- direttamente da produttori esteri ☐; (% sul totale acquistato)…………………
- da importatori italiani ☐; (% sul totale acquistato)……………………..
- direttamente da produttori italiani ☐; (% sul totale acquistato)………………

- **Ingredienti speciali e coadiuvanti tecnologici**

Ingrediente	Tipologia	Provenienza
Spezie ☐		
Miele ☐		
Frutta ☐		
Preparati enzimatici ☐		
Altro ☐		

- **Lieviti:**

-formato: liquido ☐; secco ☐
-impiego di "starter": si ☐; no ☐

- **Acquisto Lievito:**
- direttamente da produttori esteri ☐; (% sul totale acquistato)…………………
- da importatori italiani ☐; (% sul totale acquistato)……………………..
- direttamente da produttori italiani ☐; (% sul totale acquistato)………………

Denominazione	Casa produttrice	Provenienza	Prezzo €

6. SOTTOPRODOTTI DI LAVORAZIONE

- **Smaltimento sottoprodotti:**

Sottoprodotto	Produzione mensile [kg]	Destinazione
Trebbie		
Luppoli		
Lieviti		
Altro		

7. PRODUZIONE ANNUA (ettolitri)

Fino 250	☐
Tra 251 a 500	☐
Tra 501 e 1.000	☐
Tra 1.001 e 2.000	☐
Tra 2.001 e 7.500	☐
Tra 7501 e 10.000	☐
Oltre 10.000	☐

- Massima capacità produttiva annuale della struttura: ……………………………………..
- Specificare la produzione nel 2014………………………….e nel 2015……………………

7.1 Produzione: tipologie di birre prodotte (numero) …………………………………

- Stili di birra prodotta (stili conformi al BJCP 2015)

Stile	**Vol %**	**€/l**	**Stile**	**Vol %**	**€/l**
1.Standard American beer			6.A Märzen ☐		
1.A American light lager ☐			6.B Rauchbier ☐		
1.B American lager ☐			6.C Dunkel bock ☐		
1.C Cream Ale ☐			**7.Amber Bitter European**		
1.D American wheat beer ☐			7.A Vienna lager ☐		
2.International lager			7.B Altbier ☐		
2.A Intern. pale lager ☐			7.C Kellerbier ☐		
2.B Intern. Amber lager ☐			**8.Dark European lager**		
2.C Intern. Dark Lager ☐			8.A Munich Dunkel ☐		
3.Czech Lager			8.B Schwarzbier ☐		
3.A Czech pale lager ☐			**9.Strong European Beer**		
3.B Czech premium lager☐			9.A Doppelbock ☐		
3.C Czech amber lager ☐			9.B Eisbock ☐		
3.D Czech dark lager ☐			9.C Baltic Porter ☐		
4.Pale malty European lager			**10.German Wheat Beer**		
4.A Munich Helles ☐			10.A Weissbier ☐		
4.B Festbier ☐			10.B Dunkels Weissbier ☐		
4.C Helles bock ☐			10.C Weizenbock ☐		
5.Pale Bitter European lager			**11.British Bitter**		
5.A German leichtbier ☐			11.A Ordinary Bitter ☐		
5.B Kölsh ☐			11.B Best Bitter ☐		
5.C German Helles Exportbier ☐			11.C Strong Bitter ☐		
5.D German Pils ☐			**12.Pale Commonwealth Beer**		
6.Amber malty European lag.			12.A British Golden Ale ☐		

12.B Australia Sparkling Ale ☐			**19.Amber&Brown American**		
12.C English IPA ☐			19.A American Amber Ale ☐		
13.Brown British Beer			19.B California Common ☐		
13.A Dark Mild ☐			19.C American Brown Ale ☐		
13.B British Brown Ale ☐			**20. Amercian Porter and Stout**		
13.C English Porter ☐			20.A American Porter ☐		
14.Scottish Ale			20.B American Stout ☐		
14.A Scottish light ☐			20.C Imperial Stout ☐		
14.B Scottish Heavy ☐			**21.IPA (India Pale Ale)**		
14.C Scottish Export ☐			21.A American IPA ☐		
15.Irish Beer			21.B Specialty IPA:		
15.A Irish Red Ale ☐			- Belgian IPA ☐		
15.B Irish Stout ☐			- Black IPA ☐		
15.C Irish Extra Stout ☐			- Brown IPA ☐		
16.Dark British Beer			- Red IPA ☐		
16.A Sweet Stout ☐			- Rye IPA ☐		
16.B Oatmeal Stout ☐			- White IPA ☐		
16.C Tropical Stout ☐			**22.Strong American Ale**		
16.D Foreign Extra Stout ☐			22.A Double IPA ☐		
17.Strong British Ale			22.B American Strong Ale ☐		
17.A British Strong Ale ☐			22.C American Barleywine ☐		
17.B Old Ale ☐			22.D Wheatwine ☐		
17.C Wee Heavy ☐			**23.European Sour Ale**		
17.D English Barleywine ☐			23.A Berlner Weisse ☐		
18.Pale American Ale			23.B Flanders Red Ale ☐		
18.A Blonde Ale ☐			23.C Oud Bruin ☐		
18.B American Pale Ale ☐			23.D Lambic ☐		

23.E Gueuze ☐			29.B Fruit and Spice Beer ☐		
23.F Fruit Lambic ☐			29.C Specialty Fruit Beer ☐		
24.Belgian Ale			**30.Spiced Beer**		
24.A Witbier ☐			30.A Spice,Herb, Vegetal Beer ☐		
24.B Belgian Pale Ale ☐			30.B Autumn Seasonal Beer ☐		
24.C Biere de Garde ☐			30.C Winter Seasonal Beer ☐		
25.Strong Belgian Ale			**31.Alternative Fermentable Beer**		
25.A Belgian Blonde Ale ☐			31.A Alternative Grain Beer ☐		
25.B Saison ☐			31.B Alternative Sugar Beer ☐		
25.C Belgian Golden Strong Ale ☐			**32.Smoked Beer**		
26.Trappist Ale			32.A Classic Smoked Beer ☐		
26.A Trappist Single ☐			32.B Specialty Smoked Beer ☐		
26.B Belgian Dubbel ☐			**33.Wood Beer**		
26.C Belgian Tripel ☐			33.A Wood-Aged Beer ☐		
26.D Belgian Dark Strong Ale ☐			33.B SpecialtyWood-aged Beer ☐		
27.Historical Beer ☐			**34.Specialty Beer**		
			34.A Clone Beer ☐		
28.American Wild Ale			34.B Mixed-Style Beer ☐		
28.A Brett Beer ☐			34.C Experimental Beer ☐		
28.B Mix Fermentation Sour B. ☐			**Local Styles**		
28.C Wild Specialty Beer ☐			X.3 Italian Grape Ale ☐		
29.Fruit Beer					
29.A Fruit Beer ☐					

- **Formato di vendita:**

				Costo packaging €
Fusti	☐	(Specificare tipologia) …………………………………………	%sul Tot	
Bottiglie	☐	0,75 l ☐ 0,5 l ☐ 0,33 l ☐ 1,5 l ☐	%sul Tot	(bottiglia + etichetta + tappo + collarino)
Altro	☐	(Specificare)	%sul Tot	

- **Fornitura del materiale per il confezionamento:**
  BOTTIGLIE: provenienza ……………………………………………………
  subiscono qualche trattamento (sanificazione/sterilizzazione) prima dell'impiego?
  Se si specificare la tipologia: ☐ no ☐ si
  ………………………………………………………………………………………………
  FUSTI: provenienza ……………………………………………………
  subiscono qualche trattamento (sanificazione/sterilizzazione) prima dell'impiego?
  Se si specificare la tipologia: ☐ no ☐ si
  ………………………………………………………………………………………………

8. LA COMMERCIALIZZAZIONE DEI PRODOTTI

- Destinazione (% su totale della produzione)

Mercato	**Fusti**	**Bottiglie**	**Altro**
Regionale			
Nazionale			
Estero			

Specificare gli stati esteri:
……..

- **Modalità di vendita**

Modalità di vendita		**% sul tot. Produzione**
- Mescita diretta	☐	
- Distribuzione diretta	☐	
- Distribuzione indiretta	☐	
- Conto terzi (per "beer firm")*	☐	
- Altro (specificare):	☐	

***Specificare beer firm servite:**
………
………
…………………………………………………………..

- **Figure di acquirenti**

Acquirenti		**% sul tot. produzione**
Pub	☐	
Beershop	☐	
Commercianti all'ingrosso	☐	
Horeca (Hotellerie-Restaurant-Café)	☐	
Altro (specificare)	☐	

- **Tempi medi di riscossione:** ……………………………………………………………………………..

9. FATTURATO ANNO 2016

Fino a 25.000 Euro	☐
Tra 25.001 e 50.000 Euro	☐
Tra 50.001 e 100.000 Euro	☐
Tra 100.001 e 200.000 Euro	☐
Tra 200.001 e 300.000 Euro	☐
Oltre 300.000 Euro	

Specificare fatturato anno 2014…………………………….e anno 2015…………………………

Quota di fatturato annuo derivante da mescita diretta:

0 % mescita diretta	☐
Fino al 25%	☐
Tra 26 e 50 %	☐
Tra 51 e 75 %	☐
Tra 76 e 99 %	☐
100 % mescita diretta	☐

10. REGIME D'ACCISA: (D.L. 26 ottobre 1995, n.504 e successive modifiche)**:**
Accisa calcolata su:
- Volume di mosto prodotto ☐
- Birra realmente immessa al consumo ☐

Nel caso in cui l'accisa venga calcolata in base al grado Plato sull'intero "volume di mosto prodotto", partendo dal fermentatore e arrivando al contenitore finale (bottiglia, fusto etc) quanto prodotto viene perso durante i vari passaggi (tare di processo)???:

- 0 – 5 % ☐
- 6 – 10 % ☐
- 11 – 15% ☐
- > 15% ☐

11. Considerazioni previsionali sulle prospettive del settore della birra artigianale:
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
……………………

Chapter 3

New development opportunities for the craft brewing segment: the case study of a micro malthouse

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Abstract

In Italy in the past few years, the number of small breweries penetrating the craft beer sector has grown exponentially. Craft producers intend to give a strong added value and a local character to their production in different ways. One of these is the use of malt derived from small batches of local cereals and pseudo cereals. The aim of this study is the assessment of investment profitability, through a Cost-Benefit Analysis (CBA), for a compact and a modular micro malting plant in Sicily (southern Italy). The CBA for a micro malthouse was carried out considering both installation and operating costs. Net Present Value (NPV), Discounted Benefit Cost Ratio (DBCR) and Internal Rate of Return (IRR) highlight the feasibility of an investment in a compact 2-tons micro malthouse. Sensitivity analysis shows positive results of the above financial indices up to a 15% increase in the raw material costs, while with a 10% reduction of malt selling price, the same indices start being negative.

Keywords:

Malting; malting plant; cereal processing; CBA; cost-benefit analysis; Sicily; internal areas

3.1 Introduction

In recent years, several changes have characterised the European beer market. In the traditional beer-drinking countries, the share of beer on total alcohol consumption had a reduction and the reverse has occurred for the other European countries (Colen and Swinnen, 2016). Moreover, craft beer has been showing a strongly positive trend in many countries with brewing tradition, as well as in Italy, where microbreweries represent a new small segment of the agrifood sector. Historically Italian beer production was localized in the northern part of the country, counting in 1894 about 151 small and medium sized breweries (Airoldi, 2007). The number of producers decreased starting from the beginning of the 20th century, until the end of the Second World War. Few years later, Italian beer production started again: mergers and acquisitions have strongly featured the brewing sector, leading to an increasing market concentration. Three companies (Peroni, Wuhrer and Pedavena-Dreher) increased their production volumes, reaching about 60% of total national production, during the second half of the sixties (Colli, 1998).

In later years, the historical Italian beer brands were progressively acquired by foreign companies and since the nineties beer market has been, dominated by four multinational corporations (AB Inbev, Heineken, SAB Miller and Carlsberg), with few Italian companies characterised by marginal market shares (Forst, Birra Castello and Tarricone Morena). The main reason of these progressive mergers and acquisitions among competitors should be sought in the reduction of production costs and the acquisition of increasing market shares. These market conditions are favourable also for consumers who have the possibility to buy the same beer at a lower price, as an effect of the reduction of production costs achieved through the merger. Some evidences show that the reduction of beer price does not always occur after a merger. Ashenfelter et al. (2015), reported that in the US beer industry merger of brewers Miller and Coors led to price increases of about 2% and this trend was observed even more in regions where the merger had as a result the strongest market concentration.

The increasing market concentration, usually linked to mature industries, creates favourable conditions for small firms, organized with different business models, to penetrate market (Carrol, 1985; Carrol and Swaminathan, 1992, 1993, 2000; Swaminathan, 1998).

As reported in other studies (Garavaglia, 2015), the first Italian craft brewers began to brew in 1996 when market evolution changes in the consumers' preferences and some legislative innovations (Legislative Decree, 1995, no. 504) promoted the development of small breweries.

Furthermore, the increasing number of small firms derives also from consumers' growing desire to renew connections with local economies and communities, also rediscovering local traditional foods (Pratt, 2007), stimulating the supply of typical products, and thus supporting the existent productive firms (Giannetto et al., 2016; Migliore et al., 2015). This phenomenon, known as neolocalism, was observed and extensively studied in the agrifood sector (Shortrige, 1996; Shortrige and Shortrige, 1998, Schnell, 2011; Zelinsky, 2011).

It has been widely reported in the United States (US) that microbreweries have extensively contributed to the creation and maintenance of a bond to local identities, mainly through beer and brewery names, as well as through visual marketing in labels (Flack, 1997; Schnell and Reese, 2003, 2014; Holtkamp et al., 2016). Moreover, the successes of craft beers in the US market was also due to the high beer quality and the "taste revolution", aspects which both led to consumers high economic perception related to craft products (Kleban and Nickerson, 2012).

According to some authors (Fastigi et al., 2015; Esposti et al., 2016), when considering the lack of tradition in beer-making, the spread of Italian craft brewers would not seem to depend on geographical and local factors. Furthermore, also production of raw materials suitable to beer, such as malts and hops, has no tradition in Italy. The national malt productions come from few industrial malting plants (Agroalimentare sud, Melfi, PZ; Malteria Saplo, Pomezia, RM) and from the Italian consortium of barley and beer producers (COBI, Ancona). The industrial malthouses purchase and process barley from Italian farms and their production is absorbed, almost entirely, by industrial breweries. Otherwise, COBI malthouse collects barley grown by consortium members, producing different malts, and gives it back to its members who transform it into beer. The main drawback is that the malt delivered by COBI does not derive from the barley previously cultivated by its individual members, but it is a mixture of all barley harvested by members.

The structure of the craft beer sector consists of medium and small sized firms, mainly located in the northern areas of Italy, showing a substantial dependence on imports for raw materials and an average production of about 411 hectolitres (Cannatelli and Pedrini, 2012). Their productions are made in Italy, but starting from foreign raw materials, which have no local character. Beers produced by local brewers, usually considered of higher quality than industrial ones, show relevant differences in flavour, aroma, colour and foam, thus offering a wide range of beers to consumers.

The creativity of Italian brewers has led to a product diversification in various ways, such as the use of local fruits (cherries, peaches, grapes and chestnuts), herbs and spices (Savastano, 2011). This creativity has also been recognized abroad. In 2015 the first Italian-style beer, brewed using a blend of wort and grape, grape must or *sapa* (concentrated grape must), appears in the beer style guidelines proposed by the Beer Judge Certification Programs as an *Italian grape ale* (BJCP, beer style guidelines 2015).

Shepherd and Berning (2015) reported that the US craft beer industry, source of inspiration for many European craft brewers, has been characterized by greater product differentiation that requires a wider variety of malts, leading to a renaissance of micro malting industry (about 26 micro malthouses in 2014).

The presence of micro malthouses, by leading to an increase in the demand for malt, might further stimulate the growth of a local craft beer supply chain and help the development of the existent areas under cereal cultivation. Sicily, for example, is one of the most important Mediterranean regions in cereal production.

Based on the above consideration, this work aims to evaluate the economic sustainability of an investment in micro malthouses in the Sicilian (Southern Italy) agrifood sector.

In order to achieve this goal, a Cost-Benefit Analysis (CBA) was performed, both for a compact and for a modular malting plant, considering establishment and production costs.

The present paper is organised into four sections. Section 2 briefly describes the evolution of the regulatory framework of beer industry. Section 3 focuses on recent dynamics in beer market and consumption. Section 4 illustrates the technical aspects and the adopted methodology of analysis. Finally, in section 5 CBA results and sensitivity analysis are described and discussed in detail. Some consideration close the paper.

3.2 Regulatory framework

In accordance with the article 1 of the Law no. 1354 of 16 August 1962, in Italy "beer" is the product obtained by the alcoholic fermentation with *Saccharomyces Carlsbergensis* or *Saccharomyces Cerevisiae* strains of the wort prepared using barley or wheat malts (also roasted), or their mixtures and water, bittered by hop and/or his derivatives. Article no. 2 of the same law provides a list of five different categories of beers based on the degrees Plato and on volumetric alcohol content, such as non-alcoholic beer, light beer, beer, special beer and double malt beer. In brewing regulation, no relevant changes occur until '90s, and these categories, still used in labelling, have not changed during the years.

A significant change occurs in 2010 with the introduction of the Ministerial Decree no. 212. In accordance with the "ATECO 2007" classification of economic activities, proposed by the National Institute of Statistics (ISTAT), malt and beer, as well as other products, are considered as goods which are directly or indirectly related to agricultural production. In this way, malting and brewing become agricultural activities when processing at least 51% of raw material produced in the farm. In other words, an agricultural brewery processes the malt resulting, at least for the 51%, from the own barley. How above mentioned, COBI malthouse was born for the purpose of giving the opportunity for small breweries to increase the degree of product diversification by malting local cereals. Few other micro malthouses appear in Italy, probably due to the large investment in processing plants and to the lack of technological skills and maltsters. Furthermore, agricultural breweries had a streamlined taxation regime, and the existing farms were able to access the funding sources from the Rural Development Programme (RDP), financed by the European Union (EU).

In 2016, after a long debate with the Italian brewers associations, the Government fills the regulatory gap in the identification of craft beer characteristics and processes permitted in production. With the aim to promote competitiveness in agricultural and agrifood sectors, the draft Law no. 1328-B introduces some bureaucratic simplification, and craft beer was defined and regulated as *«the beer produced by small independent breweries and not subjected, during the production phase, to pasteurization and microfiltration processes»*. The definition of *small and independent breweries* is reserved to breweries, legally and economically independent from any other brewery, using their own processing plants. The maximum annual production volume, fixed in 200,000 hectolitres, includes the beer contract-brewed for third parties.

3.3 Recent dynamics in the Italian beer market

During the 2004-2015 period, national beer production was substantially stable, showing only in the last phase a slight increase. During the last four years, taking into account an annual average beer production of about 13.5 million hectolitres, and a consumption volume of about 17.8 million hectolitres, a significant import dependence for about 6.3 million hectolitres was observed. In the same last period, a growing trend was found out also for exports, reaching 2 million hectolitres; nevertheless, the trade balance had a deficit of about 4.3 million hectolitres (Assobirra, 2015).

More recently Italian beer consumption has had a slight rise, showing in 2015 about 30.8 litres of per capita annual consumption, the lowest consumption registered in the EU (Van de Walle, 2016). Craft beer production represents an emerging segment in beer industry, and beer production has generally played a marginal role in the Italian beverage industry.

Figure 1 shows the Italian craft beer consumption from 2004 to 2015, period in which some inconsistencies in the collected data have been found. A significant consumption, about 280,000 hectolitres, was recorded, for the first time in 2006, while during the following three years level was almost stable. Two peaks in craft beer consumption, observed during 2010 and 2011, were respectively 425,000 and 500,000 hectolitres. These high figures temporally coincide with the Ministerial Decree no. 212/2010 coming into force, which encourages brewers to convert their production from "*conventional*" to "*agricultural*", thus obtaining benefits such as the simplified taxation and the reduced *VAT* regime reserved to farmers. This favourable environment promotes craft beer production throughout 2011, for both active breweries and new entrants. The favourable conditions for the brewing sector, the marketing strategies and the increasing interest of media probably might explain the explosion in craft beer consumption recorded in 2010 and 2011. During the following year, consumption collapses to 261,000 hectolitres, less than the average craft beer consumed in 2006, and the number of active microbreweries, on the contrary, increases from 336 in 2011, to 407 in 2012 (Figure 1). Consumption has increased again since 2013, and in 2015 craft beer consumption represents about 2.34% (438,000 hectolitres) of the overall national (18.7 million hectolitres). In the same year, 14 industrial and 674 craft producers were active in Italy, and their production volume reached about 14 million hectolitres (Assobirra, 2015).

Craft beer sector consists mainly of three business models differing in ownership of processing plants and product distribution. The "*craft brewery* or *microbrewery*" is a small independent brewery, which brews craft beer in its own processing plant, selling its products mainly outside of the brewery, and serving craft beer directly to consumers as a marginal activity. The "*brewpub*" is a small independent brewery, which brews craft beer in its own processing plant, and sells mainly by serving craft beers directly at the brewery, which acts as a pub. The "*beer firm*" does not have its own processing plant, and sells craft beer brewed from third parties.

Based on the amount and distribution of microbreweries, brewpubs and beer firms active in Italy, table 1 shows an overview of the composition of craft beer sector, on a regional basis, in January 2016.

The sector consists of 991 players, the 50% of which are concentrated in Lombardy, Piedmont, Tuscany, Veneto and Lazio; in Sicily there are 41 producers (23 breweries, 11 beer firms and 7 brewpubs). Microbreweries and beer firms represent the most part of market players, while brewpubs account for less than 15%, and are not operating in all the Italian regions. An increasing number of new entrepreneurs considered craft brewing as an interesting source of profit, but the substantial investment required for processing plant induced investors to start their business through contract-brewed beers. About the 70% of the Italian market players is equipped with his own processing plant, and they produce craft beer also for beer firms, which currently represent a significant share of market supply.

As a result, the Italian brewing sector appears concentrated and dominated by few big industries, producing lager, filtered and pasteurized beer. The Italian craft beers show a high number of brewers and a strong degree of product diversification.

3.4 Material and methods

In order to evaluate whether in a so fast growing segment of beer industry, craft brewing could be a convenient business, the present study was carried out with the aim to assess the feasibility of a micro malthouse in Sicily, an Italian region with a long tradition in cereal production.

The feasibility assessment of the investment focused on the economic and financial analysis by comparison of two different malting equipment, a compact and a modular micro malting plant, able to process 2 tons of raw materials per cycle.

Technological aspects and project ideas

Malting process consists of three different phases: steeping, germination and kilning. During the steeping phase, cereals are subject to various cycles of soaking and drainage (24/48 hours). The germination process is carried out with 95% of relative humidity over 4 or 5 days, depending on raw material characteristics. During the last phase of the process, cereals are dried until reaching a water content of less than 6% in dry matter. Time required to complete kilning phase depends on raw material characteristics and type of the obtained malt, but generally the whole malting process ranges between 6.5 and 7.5 days.

Our project plan considers the production of barley and wheat malts, accounting respectively for 70% and 30% of the overall production volume. In the case study, assuming that the whole process

(1 cycle) is carried out over 7.5 days, the malting operation was planned considering the production of basic (pilsner or pale ale type) and special (caramelized type) malts. The yield of process, according to the instructions supplied by the equipment manufacturers, is equal to 80% of the raw materials' original weight.

The compact micro malting plant carries out the whole malting process on a single device by using an "all-in, all-out" system. This system allows it to prevent the breakage of the steeped cereals by reducing their handling, which makes it ideal for processing naked cereals, such as wheat.

The modular malting plant consists of two devices: a steeping vessel and a germinator/drier. The external steeping vessel enables it to increase the monthly productivity by reducing downtime between two consecutive batch processing. Table 2 shows the amount of raw materials processed each month, and the annual malt production of the selected malting plants.

The Cost-Benefit Analysis

The revenues obtained from malt sale represent the gross benefit (GB) of the malthouse management. Since annual production is scarce and micro malthouses are nearly absent in Italy, it is reasonable to observe a limited availability of structural data. Knudson (2014), in a recent study assessing the feasibility of malthouses in Michigan (USA), reports a price of about $1,100.00 per ton for a malthouse producing about 200 tons of malt per year. A micro malthouse producing different malt types and focusing on quality will not be able to offer a competitive malt price compared to industrial companies exploiting scale economies. With regard to the case study, considering that the selected malting plants show less than 50% of the annual productivity reported above, for a prudential estimate we assume a malt-selling price of 1,600.00 € t^{-1}, regardless of malt type.

The analysis was carried out by taking into account 15 years of investment term and considering both the equipment installation and the operating costs.

The estimation of installation costs was carried out through an estimative metric computation, according to a certified price-list for works and investments in agricultural and forestry companies, published by Sicilian Regional Government (Decree no.11, *Gazzetta Ufficiale della Regione Sicliana, 13 March 2015)*. The malthouse production lines were chosen to achieve an amount of production that might ensure a reasonable profitability, identifying the cost of malting equipment as the price quotation provided by suppliers. Furthermore, a designing cost was accounted in the rate of 7% of the overall installation cost.

In order to identify the monetary costs necessary to perform a malting activity, information was gathered from relevant literature (Knudson, 2014; Shepherd and Berning, 2015). The assessment of energy and raw materials requirements was made possible by collecting the data available on the EUROMALT website (Association of the main maltsters of the European Union).

The maintenance and insurance costs were accounted respectively in the rates of 4% and 2%, in terms of malting equipment and building costs. The building depreciation charge was considered in the rate of 2.5% on the plant reconstruction cost. Depreciation charge of malting devices was not calculated because, although operating till the end of the investment term, they will need to be replaced due to obsolescence. With regard to manpower, malting is not a labour-intensive activity and the amount of labour needed is relatively small: according to production requirements, the micro malthouses occasionally hire some part-time workers. However, in order to obtain a prudential estimate of the annual operating cost, according to the national collective bargaining agreements, for the food-industry workers (*Tabella dei minimi, Contratti Collettivi Nazionali di Lavoro*, 1st January 2016), 14 monthly wages per year are due to a full-time worker (third level wage). We assumed a further cost related to managerial and administrative work in the rate of 4% calculated on gross benefit. In consideration of the diversified taxation system related to the business typology, costs and revenues were accounted excluding taxes. The passive interests payable on short-, medium- and long-term debt were accounted on working capital (4% interest rate), malting equipment (5% interest rate) and building construction costs (2% interest rate) respectively.

The cash flows for each year were calculated and benefits and costs were discounted by using a 5% rate, which was considered reasonable based on the investment amount and riskiness.

The comparative analysis was carried out by calculating the most common financial indices reported in literature, such as the Net Present Value (NPV), the Discounted Benefit Cost Ratio (DBCR) and the Internal Rate of Return (IRR), as described in other studies carried out in the Sicilian area (Asciuto et al., 2002; Sgroi et al., 2015; Pappalardo et al., 2017).

3.5 Results

Drawing attention to the prudential nature of our estimates, the results of the comparative analysis show a financial advantage for the malthouse equipped with a compact processing plant.

The passive items of the installation costs were calculated and reported in table 3.

In our case study, although the building construction expenses were calculated, as an alternative the maltsters may rent the building to carry out their activity, accounting a smaller rent expense in the annual operating costs.

The different technology of the two malting equipment affect the malthouse installation costs. Compact and modular processing plants represent more than 52% and 70% of the total investment required, estimated respectively for 3,876.6 and 6,051.1 € t^{-1} (Table 3).

Net Benefits (NB) which can be obtained by selling malt at the price of 1,600.0 € t^{-1}, were reported in table 4.

The NB amounts, calculated considering the production of malts based on compact and modular devices, were respectively 444.8 and 284.6 € t^{-1}. With regard to production costs (PC), the two systems show a different behavior, since for the malting plant with a compact device PC were calculated equal to 1,155.2 € t^{-1}, while for the modular devices PC were equal to 1,315.4 € t^{-1}. Since we are dealing with an agrifood industry and market conditions are considered constant during the whole period, raw materials and energy required by the process account for a relevant share on the annual operating costs. These examined processing plants transform the same quantities of cereals per cycle by using comparable energy levels, and these items together represent a share of over 47%

and 42% of total production costs, respectively for the compact and the modular systems. At the start of the business, the achievement of quality cereals suitable to malting could be quite difficult. In this regard, the maltsters in order to purchase cereals suitable for malting, might be obliged to negotiate on quality characteristics and bargain prices with the farmers who might ensure a local supply chain.

The other elements that largely contribute to production costs were represented by the maintenances and insurances, wages and interests. For the compact processing plant, maintenances and insurances represent less than 10% of total costs, while a passive of 226.0 € t^{-1} was accounted as wages and social charges (over 19.5% of total costs). In the case of the modular system, maintenances and insurances affect the passive for 197.5 € t^{-1}, and the same amount is due to wages and social charges. In both case these last two items account for about the 30% of the costs required to produce a ton of malt.

Whit regard to interests, the significant differences for the investments related to the acquisition of processing plants, lead to a wide range of values; for the modular system this passive item, estimated in 251.0 € t^{-1}, represents a 19% share of production costs. On the contrary, for the compact processing system the passive interests amount to less than 12.5% of production costs.

The results of the financial analysis, reported in table 5, show relevant differences for the indices calculated on both malthouse systems.

The financial analysis indicates the viability of the compact system, which shows a NPV of 501.25 €, an IRR of 7.06% and a DBCR of 1.03. The same indices, when calculated for the modular system, were negative and equal to -3,079.95 € for the NPV, -5.1% for the IRR and 0.83 for the DBCR. The DBCR, which represents a profitability index, has led to values higher than 1 only in the case of the compact processing plant. The higher annual productivity of the modular devices does not justify the major investment required for the acquisition of this processing plant. These first results show that only one of the analyzed systems is viable, and despite the lower productivity showed by the compact system, the financial indices indicate the profitability of an investment for a malthouse.

The sensitivity analysis

With the aim to assess the stability of the above results, a sensitivity analysis was performed by varying on one side the malt sales price and on the other side the costs of the required raw materials. These two parameters were modified one by one upwards and downwards, by 5%, 10% and 15%. On the basis of the above hypothetical scenarios, the new financial indices were obtained for both systems, whose results in relation to malt sales price change are illustrated in table 6.

With regard to the compact system, a 15% increase produces significant changes for the indices (NPV 2,672.09 €; IRR 14.93%; DBCR 1.18), while simulating a reduction of only 5% in malt price, results were negative (Table 6). Despite a +15% variation in malt price, the modular malting system continues to show negative indices (NPV -908.69 €; IRR 2.43; DBCR 0.95).

Table 7 shows the financial indices calculated when varying market price for raw materials.

The micro malthouse equipped with the compact device had positive results also with a 15% increase in the raw materials prices (DBCR 1.01), and shows a NPV of about 885.58 € in the reverse case. Even in the latter hypothesis, the results of the modular system were negative.

3.6 Conclusions

Few industrial companies producing filtered and pasteurized lager beers currently dominate the Italian brewing sector and microbreweries, beer firms and brewpubs represent only a marginal but increasing share of beer market. The craft beer production in Sicily, as well as in many other Italian regions, represents a recent and fast-growing sector, sensitive to the new consumption trends, despite the strong dependences from raw material imports. In accordance with the recent regulatory updates, malt production and its processing into craft beer have enriched the range of products connected to agricultural and agrofood activities. The presence of local maltsters could be a valuable tool to increase the added value of local products, following the trend in production sustainability (Schimmenti et al., 2016). In this regard, Sicily represents a region which has been playing a traditionally important role in the Italian cereals production, and more in general in the Mediterranean area.

In the present work the potential feasibility for micro malting systems, currently missing in Sicily and not widespread in Italy, was assessed; the above mentioned systems may represent the link between farmers and brewers in the promotion of local products with unique characteristics and a strong connection with the production areas.

The results have pointed out that size and typology of processing plants play a key role for the economic and financial feasibility of a malthouse. It could be interesting, for further research developments, to assess whether the investment profitability for the modular processing plant could be enhanced through a production diversification, such as to grow barley and/or to brew their own malts.

On this subject a valuable tool, able to encourage the growth of a local chain for craft beers, could be represented by the 2014/2020 Rural Development Programme for Sicily. The identification of the most appropriate programme measures, supporting the local market segment of malting and brewing sector, should be combined with the improvement of the professional operators’ skills.

In this regard, according with Mitchell et al. (2014), technical specialists could play a key role as knowledge gatekeepers, facilitating the knowledge flow, bridging the technological gap and innovating the new segment of enterprises.

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Table 1. Structure and composition of the Italian craft beer sector in January 2016

Regions	**Brewery**	**Brewpub**	**Beer firm**	**Regional total**
Lombardy	84	29	54	**167**
Piedmont	56	11	24	**91**
Tuscany	54	9	21	**84**
Veneto	39	16	25	**80**
Lazio	37	7	36	**80**
Emilia-Romagna	30	10	34	**74**
Marche	33	5	18	**56**
Campania	34	6	14	**54**
Apulia	24	9	17	**50**
Sicily	23	7	11	**41**
Trentino South Tyrol	16	12	5	**33**
Abruzzo	22	0	11	**33**
Friuli Venezia Giulia	17	8	7	**32**
Sardinia	21	4	4	**29**
Liguria	18	6	2	**26**
Umbria	16	3	4	**23**
Calabria	11	3	4	**18**
Molise	5	0	3	**8**
Basilicata	7	0	1	**8**
Aosta Valley	2	1	1	**4**
National total	**549**	**146**	**296**	**991**

*Source:*microbirrifici.org

Table 2. Productive characteristics of malting equipment (t year^{-1})

Equipment	Processed wheat	Processed barley	Malt production
Compact	28.4	67.2	76.8
Modular	33.6	76.8	88.3

Table 3. Malthouse installation costs (€ t^{-1})

Items	**Compact**	**Modular**
Building	1,604.8	1,402.2
Processing plant	2,018.2	4,253.0
Designing	253.6	395.9
Total project	**3,876.6**	**6,051.1**

Table 4. Determination of the annual net benefit (€ t^{-1})

Items	**Compact**	**Modular**
Malt price	**1,600.0**	**1,600.0**
Costs:		
Raw materials	269.3	269.4
Packaging	20.0	20.0
Energy	281.1	280.9
Maintenance and insurance	112.0	197.5
Building Depreciation	40.1	35.1
Wages and social charges	226.0	197.5
Managerial and administrative work	64.0	64.0
Interests	142.7	251.0
Total cost	**1,155.2**	**1,315.4**
Net benefit	**444.8**	**284.6**

Table 5. Financial indices

Index	Compact	Modular
NPV (€)	501.25	-3,079.95
IRR (%)	7.06	-5.10
DBCR	1.03	0.83

Table 6. Results of the sensitive analysis by varying malt selling price

Index	5%	10%	15%	-5%	-10%	-15%
			Compact			
NPV (€)	1,224.67	1,948.38	2,672.09	-222.76	-946.47	-1,670.18
IRR (%)	9.84	12.45	14.93	4.04	0.68	-3.24
DBCR	1.08	1.13	1.18	0.98	0.93	0.88
			Modular			
NPV (€)	-2,356.11	-1,632.40	-908.69	-3,803.54	-4,527.25	-5,250.97
IRR (%)	-2.30	0.18	2.43	-8.53	-12.96	-20.19
DBCR	0.87	0.91	0.95	0.79	0.75	0.71

Table 7. Results of the sensitive analysis by varying raw material costs

Index	5%	10%	15%	-5%	-10%	-15%
Compact						
NPV (€)	372.75	244.54	116.33	629.16	757.37	885.58
IRR (%)	6.54	6.02	5.49	7.56	8.06	8.56
DBCR	1.03	1.02	1.01	1.04	1.05	1.06
Modular						
NPV (€)	-3,208.08	-3,336.34	-3,464.59	-2,951.57	-2,823.32	-2,695.06
IRR (%)	-5.69	-6.26	-6.85	-4.60	-4.08	-3.58
DBCR	0.82	0.82	0.81	0.84	0.84	0.85

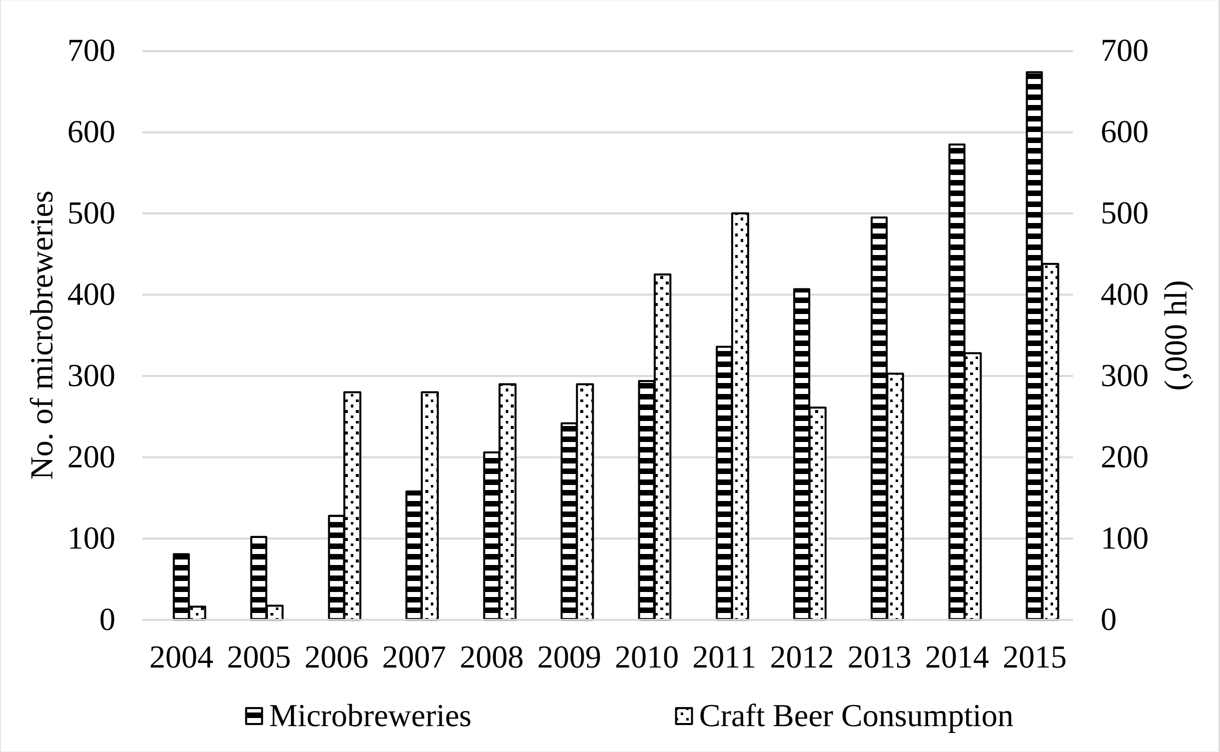

Figure 1: Italian craft beer consumption and number of microbreweries active by year (*Source*: Assobirra, excluding beer firms).

APPENDIX

Photographs of the malting equipment

Compact micro malting plant

Source: http://www.bbcinox.it/micromalteria.html

Modular micro malting plant

Source: http://www.kaspar-schulz.de/en/innovations/malt-production/malting-systems/malting-systems.html

Chapter 4

Preliminary Evaluation of Durum Wheat (*Triticum Turgidum* Subsp *Durum*) During Malting Process

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Abstract

Durum wheat (*Triticum turgidum L.* subsp. *Durum Desf.*) malt obtained from a traditional Italian cultivar called “Simeto” (Capeiti x Valnova; tetraploid, 2n = 28) was studied and evaluated for the malt quality characteristics. Two different final drying temperature of 45 and 70 °C were tested for durum wheat (SM45 and SM70), using also a common wheat (CWM) as a control test. To evaluate the wort characteristics, and how non-starch polysaccharides (NSP) affect the wort viscosity, wheat malts were employed in rate of 40% with commercial barley malt (BM) under EBC congress mash conditions. SM45 and SM70 were characterized by lower solubility for betaglucans (BG) and high levels of water extractable arabinoxylans (WEAX). Alpha and beta amylases, *endo*-1,4-β-D-glucanase and *endo*-1,4-β-D-xylanase activities detected on SM45 were higher than SM70 and CWM, likely due to the combined effects of the cultivar characteristics and the low temperatures used during the kilning phase. When $SM45_{40\%}$ and $SM70_{40\%}$ were used the derived worts have had lower color, FAN levels, saccharification time, beta-glucans (WBG) and viscosity than $CWM_{40\%}$. These first results indicate that durum wheat has good characteristics and can be suitable for brewing purposes.

Keywords:

Durum wheat, malting, enzymes, brewing processes

4.1 Introduction

In Italy, over the past decade, the number of breweries and micro-breweries has grown exponentially to the interest in beer production with unusual cereals and pseudo cereals (Mayer et al 2011). The most represented cereal crop of the southern regions in Italy is durum wheat (*Triticum turgidum L.* subsp. *Durum Desf.*), commonly used for pasta and bread making. Common wheat (*Triticum aestivum L.)* was, and still is, used in northern Europe as a source of fermentable extract for beer production and malting and brewing processes have been extensively studied by several researchers (Faltermaier et al 2015, 2014; Wu et al 2015). However, few researchers have studied durum wheat malting and brewing processes (Suhasini et al 2004; Mascia et al 2015).

During malting processes specific enzymes hydrolyze and degrade proteins, starch and non-starch polysaccharides (NSP) and this gradual molecular weight reduction continues during the brewing process.

Wheat characteristics, such as proteins, starch and NSP directly affect the malt quality. Proteins play an important role in malting wheats, recommended values ranged from 11 to 13% of db (Faltermaier et al 2014). High nitrogen levels in malt are inversed related to extract and soluble proteins but good malt characteristics can also be obtained facilitating the protein degradation by extending the germination phase (Jin et al 2014). The protein degradation degree (Kolbach index), calculated as the ratio between soluble and total nitrogen, is normally taken into account to monitoring the germination process and the kernel degradation. High Kolbach index values are an indication of extensive protein degradation and results in high respiration rates that cause increasing malting loss (Jin et al 2012).

Malting suitable cereals need to have 50-75% of starch (Jin et al 2011) with NSP that represent the main constituents of cell wall of the cereal’s endosperm. In wheat, arabinoxylans account more than 66% of the endosperm cell wall and can reach about 7% of the whole kernel weight (Faltermaier et al 2014). Beta-glucans in wheat are less represented than in other cereals, their structure consisting mainly of trisaccharide units with more regular structure than beta-glucans from other cereals and this fact makes it less water soluble (Cui et al 2000).

The presence of high-molecular-weight NSP levels in malts can result in reduced extraction efficiency, high viscosity with consequent poor filterability and haze formation in worts and beers (Debyser et al 1997, 1998; Lu et al 2006). Because of their high arabinoxylans content these problems are marked when wheat or wheat malt were used as adjunct (Lu et al 2006).

This preliminary work was aimed to investigate the suitability of durum wheat for malting and brewing processes and to evaluate how genotype and different kilning end temperature affect the malt quality attributes. Furthermore the effects on worts characteristics was also studied for different grist blends prepared with different recipes: 1) 60% of commercial barley malt (BM) and 40% of durum wheat malts ($SM45_{40}$); 2) 60% of BM and 40% of durum wheat malts ($SM70_{40}$); 3) 60% of BM and 40% of common wheat malts (CWM_{40}).

4.2 Materials and Methods

Raw Material

"*Simeto*" (*Triticum turgidum L. subsp. Durum Desf.*, pedigree: Capeiti x Valnova; 2n = 28) and "*Vivant*" (*Triticum aestivum L.*, pedigree: Boxer x Gawain, 2n = 42) wheat samples, grown and harvested in 2015, were supplied by a commercial cereal farm. Commercial pilsner barley malt (BM) was also used.

Malting Conditions

Malting tests were performed in triplicate using a stain steel micro malting plant equipped with steeper, germination drum and kilner (Laboratory of Food Technology at the Department of Agricultural and Forest Science, Palermo, Italy). All processes are managed by PLC controller. A final steeping degree of about 40% has been reached by soaking grains twice in water at 15 °C, respectively for 6 and 4 hours of steeping and 8 h of air-rest. The samples were germinated 120 h at 15 °C and 95% of RH. The germinating grains were carefully dried with initial air-on temperatures of 35 °C for 8 h, followed by 16 h at 45 °C before reaching the end temperature of 70 °C for 9 h. A constant drying temperature of 45 °C for 25 h was also tested, while maintaining the previous phase at 35 °C to study the effects of the low drying temperatures on the enzyme activities.

Mashing tests

Malts were milled to pass 0.2 mm sieve, using a Buhler Miag disc mill. Three different grist blends were prepared using 60% of BM and 40% of the obtained durum and common wheat malts. EBC Congress mash conditions were used to obtain the worts used for the analyses.

Raw Material, Malt and Wort Analysis

The moisture content, thousand kernel weight (TKW), germination energy (GE), proteins, beta-glucans (BG), color, extract, free amino nitrogen (FAN), saccharification time, pH and viscosity of raw materials, malts and worts were carried out according with Analytica EBC methods (2010). The Kjeldahl method was employed for total and soluble proteins determinations, using a nitrogen conversion factor of 5.7 for wheat and 6.25 for barley. Kolbach index was calculated as a ratio of soluble to total nitrogen content. Whole starch content was measured using an enzymatic kit (Megazyme, Ireland) according to AOAC method (2005). The starch hydrolysed during malting process was determined as the differences between raw material (RM) and correspondent malt (M), the final starch content was expressed as % of dry matter ($\Delta\%$ starch = %RM - %M). Quantitative determination of high molecular weight beta-glucans was performed by an enzymatic kit (R-Biopharm AG, Germany).

Total, Water Extractable and Wort Arabinoxylans

Total (AX), water extractable (WEAX) and wort (WAX) arabinoxylans were determined by gas-liquid Chromatography (ThermoQuest, model Trace 2000 series, Rodano, Italy) using a flame ionization detector and a RTX-225 column (30 m, 0.25 mm ID, 0.2 µm film thickness). According with Debyser et al (1997), malt flours were heated at 130 °C in oven during 5 h to eliminate enzyme activities before carrying out the WEAX extraction. The water suspensions, prepared by stirring 2 g of pre-heated samples (1/10 w/v) at 30 °C for 2 hours, were hydrolyzed after centrifugation (3000*g*, 15 min.). AX, WEAX and WAX hydrolysis were performed by 2.0 M trifluoroacetic acid (120 minutes at 110 °C). The alditol acetates were prepared following the method proposed by Englyst and Cummings (1984). The separation of the alditol acetates was carried out at 225 °C, the carrier gas was He (flow rate 1.5 mL/min) and the internal standard was β-D-allose.

Enzyme Activities

β-glucazyme tablets were used to determine the *endo*-β-glucanases activities (Megazyme, Ireland). The *endo*-1,4-β-D-xylanase activity was measured via xylazyme tablets (Megazyme, Ireland). The malt amylase test kit (Megazyme, Ireland) was used to quantify α and β amylases in malt flour. All the enzyme activities are expressed as units per grams of dry matter (U/g). One U of activity is defined as the amount of enzyme required to release one micromole of reducing-sugar equivalents per minute under the defined assay conditions.

Viscosity

A falling ball automatic micro viscometer (Anton Paar GmbH, Graz, Austria) was used to measure the kinematic viscosity of the EBC congress worts.

Statistical Analysis

Analysis of variance (one-way ANOVA) and principal component analysis (PCA) were performed using MATLAB software (MathWorks, version 8.5.0).

4.3 Results and Discussion

Raw Materials

Table 1 shows the main characteristics for *Simeto* and *Vivant* wheat grains. The TKW values were higher for durum wheat, 43.6 g db then common wheat 38.7 g db. *Simeto* variety shows larger size and vitreous structure than *Vivant*. The observed protein and starch levels were comparable for both genotypes (Table 1). With regard to NSP, BG levels were consistently low and the main NSP observed in wheats were arabinoxylans. *Simeto* had higher AX levels and A/X ratio than *Vivant*, respectively 4.9 % of db with A/X ratio of 0.68 and 3.9 % db with A/X ratio of 0.63. These results are in accordance with those proposed for durum wheat in other research (Ciccoritti et al 2011). The germination energy (GE %) was high for both wheats, the observed values were about 97 %. High

GE is important for the economic sustainability of the malting process, low GE values are index of high levels of ungerminated grains.

Wheat Malts

The malts quality parameters are shown in table 2. Because of the low drying temperature, SM45 had the highest moisture content, about 5 %, followed by SM70 and CWM. The observed moisture levels were in the range of recommended values reported in a recent review for the use of common wheat as a brewing cereal (Faltermaier et al 2014).

The color of the finished malts were really pale, comprised between 3.0 - 4.0 EBC units and SM45 was the paler wheat malt.

Extract levels (Table 2, Extract %) in congress wort were similar between samples and also similar with that reported in other research (Jin et al 2008, 2011, 2012). Soluble proteins (% db) for SM45, SM70 and CWM ranged between 3.6 and 4.2 % on db, and not significant differences were found for durum and common wheats. The free amino nitrogen (FAN, mg/100g of db), that represent the amount of free amino acids, ammonia and small peptides, show different trends for all the samples. CWM had the highest level followed by SM45 and SM70 (see table 2), that have had statistically different ($p < 0.05$) FAN content. The differences in FAN levels from CWM were marked, about 15 and 28 mg/100g on db respectively for SM45 and SM70. This can be revealed as a stronger protein degradation for CWM also if the soluble proteins were comparable for all the samples.

During malting process, due to the amylase activities, starch was partly hydrolysed and the whole starch content decrease. The starch levels observed for SM45, SM70 and CWM were comprised between 57 and 60 % on db, showing no relevant differences between samples. The analytical method for starch determination involves the removal of sugars, by washing the samples with ethanol, the differences between raw material and correspondent malt starch content can represent the hydrolyzed starch (Δ% starch). Figure 1 shows the trend for starch degradation, expressed delta starch (Δ%). As we can observe in figure 1, Δ % starch had a similar trend than the Kolbach index (table 2).

The decrease in starch content for CWM was about 1.5 and 9 times that observed for SM45 and SM70. The index of proteins degradation show high variability, CWM had the higher value, SM45 and SM70 have had respectively 40.3 and 38.1 %. Considering that the different wheats, with comparable protein and starch levels (see table 1), have been steeped and germinated under the same conditions, probably the wheat genotype influences the extension of the degradation processes.

After malting processes, the AX malt content coincided with AX value determinated on wheat raw material; WEAX levels ranged between 0.71-1.05 % on db and the BG content for all the samples was negligible. CWM showed lower WEAX than both durum wheat malts and the arabinose to xylose ratios were not significant different for all the samples (table 2). In accordance with Guo et al. (2014), a high portion of wheat arabinoxylans, were found to be water insoluble. As previously said, AX represent the main cell walls polymers of the starchy endosperm, also if CWM had the higher starch degradation, the WEAX level was lower than in the other samples.

Enzymes Activities

Endo-β-glucanase

The degradation of the barley and wheat β-glucans during malting and mashing is due to the action of specific enzymes, such as the β-glucan solubilases and the endo-β-glucanases (endo-1,4β-glucanase, malt β-glucanase and non-specific endo-1,3-β-glucanases which hydrolyse 1,4-β-linkages next to a 1,3-β-linkage). These lasts endo-enzymes were found to be inactivated after 15 minutes at 50 °C (Debyser et al 1998; Denault et al 1981), but the β-glucan solubilases are still active above this temperature (Bamforth et al 1981). The high molecular weight β-glucans released during the last part of the mashing are no longer degraded (Debyser et al 1998). Despite the low β-glucan levels found for all the wheat malts, not negligible endo-β-glucanase activities were detected (table 3). How reported by Kunauchi et al (2011), endo-β-glucanases catalyze the hydrolysis of β-1,4 bonds, producing oligosaccharides with a single β-1,3 linkage and diversified number of β-1,4 linked glucosyl units (Varghese et al 1994). In our tests, the β-glucan degrading activities were found to be significantly different ($p < 0.05$) for all the samples. In dried malts, endo-β-glucanase ranged between 1.3-14.9 U/g, CWM showed activity values 8 and 11 times less respectively for SM70 and SM45 (table 3). As expected, the sample with the highest activity was SM45 (table 3). The low drying temperature maybe preserves enzymes, but probably the genotype may influence mainly the glucanase levels as we observed in the value of enzyme activity in CWM and SM70. The endo-β-glucanases level detected for BM was about 31.1 U/g, similar values were reported in other research (Toffoli et al 2003).

Endo-1,4-β-D-xylanase

Three groups of enzymes play a key role in arabinoxylans degrading processes, such as endoxylanases, β-D-xylosidases and α-L-arabinofuranosisases. After the action of the endoxylanases, high molecular weight arabinoxylans are degraded into xylo-oligosaccharides, that are further degraded by β-D-xylosidases and then by α-L-arabinofuranosisases. In malting cereals, the enzymes involved in hydrolysis and degradation of arabinoxylans are produced at the end of the germination process (Banik et al 1997). Li et al (2004), have reported that the endoxylanase activity detected on finished malt was about the half of the maximum activity observed after 72 h of germination. Table 3 showed the endo-1,4-β-D-xylanase activity of dried wheat malts. No significant differences were observed for the enzyme activity of durum wheat malts that showed the highest values. CWM had the lowest level (0.11 XU/g). Debyser et al (1997), show that most of the arabinoxylans in wort originates from the WEAX of the malt, and the further solubilisation of pentosans during brewing depends on the endoxylanase activity present in malt. In our wheat malts, a positive correlation was also observed for endo-1,4-β-D-xylanases and WEAX, in particular for wheat malts when the enzymes activity increase, the arabinoxylans show more water solubility. Considering the different levels of endo-1,4-β-D-xylanase and WEAX, detected in durum and common wheat malts, probably this behavior is influenced also by genotype. The wort and beer filtration problems, due to the arabinoxylans solubilized by endoxylanases during mashing are partially reduced by the pentosans degradation to small oligomers operated by the same enzymes

(Debyser et al 2011). Furthermore, endoxylanases were found to be more heat stable than the other two groups of arabinoxylan degrading enzymes (Preece et al 1958).

Malt Amylases

Amylolytic enzymes levels for wheat malts were shown in table 3. The β-amylase attacks alternate 1-4 linkages from the non-reducing end of the starch molecule. This enzyme is present in free, insoluble and latent form in unmalted grains (Evans et al 1997). The insoluble and latent form of β-amylases, bound *via* disulphide bridges to protein compounds, are released through proteolytic activity during the germination (Faltermaier et al 2014). The observed range for β-amylase activities was between 34.7-58.2 BU/g. The wheat malts show significant differences ($p < 0.05$), in particular SM45 and SM70 registered the higher values than CWM. Taking into account that SM70 and CWM were malted using the same malting regime, probably the genotype affect the availability of the β-amylases.

The α-amylase cuts the α-1,4 linkages from the inside, degrading amylose and amylopectin to dextrins. Differently from the β-amylase, α-amylase is synthesized during the germination process in the aleurone cells (Faltermaier et al 2014). The α-amylase activity shows the same behavior observed for the β-amylase, with the values of the durum wheat malts more than two times higher than CWM. Nevertheless CWM showed the highest value of starch degradation (Δ %), their amylolytic activity was significantly the lowest. SM45 shows the highest α-amylase level (149.9 CU/g), confirming that drying malt at low temperatures increase the enzymes activity, due to the continued germination during this last phase (Bathgate et al 1973; Phiarais et al 2005). The α-amylase level detected for CWM was similar to the activity reported in other research and relative to wheat malt (Jin et al 2008). The high variability showed for the amylases activities of durum and common wheat malt does not seem to affect the extract levels, which were comparable between samples (table 2).

Effect On Wort Characteristics Testing Grist Containing 40% Wheat Malts.

The characteristics of the worts brewed using 100% BM and three different grist blends are illustrated in table 4. The wort color was comprised between 8.9 and 11.3 EBC units, CWM_{40} had the darker wort and both the durum wheat malts have had paler than BM_{100}.

The revealed extract of EBC congress worts, expressed as % on db, were comprised in the range 80.5-83.3. The lowest level was detected for the wort brewed with 100% BM meanwhile CWM_{40} showed the highest level, similar values were observed for $SM70_{40}$ and $SM45_{40}$.

Regarding FAN contents sample CWM_{40} showed a value of 122.4 mg/100g higher than $SM45_{40}$, $SM70_{40}$ and BM_{100} respectively. The saccharification time ranged between 5 and 10 min, employing CWM_{40} we found an efficiency decrease in sugar conversion, probably due to the low amylolytic activities observed for common wheat malt. The pH values were almost the same for all the samples, only BM_{100} showed lower value but also comparable with the other samples.

The WAX values ranged from 429.2 to 592.6 mg/100g, respectively for BM_{100} and $SM45_{40.}$ The WAX value of sample CWM_{40} was comparable with the value of durum wheat malt dried at 45° C. $SM70_{40}$ showed the lowest content, significantly different ($p < 0.05$) from values observed in other worts. The A/X ratios determinated on WAX, were similar for all the samples with values between 0.53-0.57. The differences found for WEAX from single malt could indicate that mashing could affect the structure of arabinoxylans. BM_{100} and $SM70_{40}$, that have had less WAX solubility, show also high degrees of arabinose residues substitutions (at O-3 or both at O-2 and O-3 on the β-(1→4) xylose backbone). All the worts were brewed using the EBC congress mashing conditions. We observe that, the addition of wheat malts affect positively the WAX release. The data show the peak levels when common wheat malt was used. This is probably due to the combined effect of genotype and malting conditions (see table 3).

The WBG values showed for sample BM_{100} an average of 280.5 mg/100g, meanwhile samples CWM_{40}, $SM70_{40}$ and $SM45_{40}$ showed significantly lower content. ($p < 0.05$). When 40% durum wheat malts were used in mash the BG levels were considerably lower than those observed in grist containing common wheat. The different β-D-glucanase activities (see table 3), decrease from SM45 to CWM, affecting the availability of WBG during mashing.

The worts kinematic viscosities, expressed as mPa.s, was higher for sample CWM_{40} that show an average value of about 1.6 mPa.s. $BM_{100,}$ $SM70_{40}$ have had similar trend and $SM45_{40}$ show a significantly lower viscosity of about 1.47 mPa.s ($p < 0.05$).

With the aims to evaluate the influences of NSP on wort viscosity, a principal component analysis (PCA) was performed using WBG, WAX, A/X ratio and viscosity as variables. Two principal components (PC) were selected, explaining 73.66 % of the variances, respectively 43.26% from the PC1 and 30.40% from the PC2. The PC1 was positively characterized by WBG, viscosity and A/X. The PC2 was positively characterized by the WAX. The biplot (figure 2), showing scores and loading of the PCA results, evidenced that the use of 40% of different wheat malts, differently affect the worts characteristics. Also if EBC congress mash conditions were employed for all the tests, the worts characteristics showed different behavior and the samples scores were located in different clusters (figure 2).

BM_{100} was characterized by high WBG and A/X levels, CWM_{40} show high WBG, WAX and viscosity. On the contrary $SM70_{40}$ and $SM45_{40}$, plotted away from the other samples, were characterized by low WBG, WAX and viscosity than the others samples.

4.4 Conclusions

This preliminary study investigates on the characteristics of durum wheat malts, testing the suitability for malting and brewing processes. Genotype and different kilning end temperature affect the malt quality attributes, mainly in term of extractable compounds and enzyme activities. For durum wheat malts, at 45 °C of final drying temperatures positively affects Kolbach index, FAN and levels of enzyme activities and does not seem to influences the availability of NSP in finished malts. Comparing SM70 and CWM, the common wheat had the strongest degradation, both for proteins and starch, but showing the lowest enzyme levels.

When the 40% of wheat malts was used in mashing, the level of Extract, FAN and WAX increase. Durum and common wheat malts show substantial differences for the availability of WBG and the wort viscosity. Also if CWM and SM70 were malted following the same conditions, when were used in rate of 40% of the grist, their mashing performances follows different trends. The use in mashing of 40% of durum wheat malt result in low viscosity and reduced availability of WBG.

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Table I. Quality characteristics of durum and common wheat

Parameters	***Simeto* durum wheat**	**Common wheat**
Moisture [% w/w]	7.0±0.2	10.3±0.2
TKW [g on db]	43.6±0.1	38.7±0.5
Protein [% db]	10.7±0.1	11.2±0.1
Starch [% db]	61.2±0.9	63.3±1.1
BG [% db]	0.18±0.1	0.14±0.1
AX [% db]	4.9±0.0	3.9±0.5
A/X	0.68±0.01	0.63±0.06
G.E. [%]	97.6	97.0

TKW = thousand kernel weight; BG = betaglucan content; A/X = arabinose/xylose ratio AX = total arabinoxylans content; G.E = germination energy; all values are expressed as means ± standard deviation (n = 3)

Table II. Quality characteristics of durum (SM45 and SM70), common (CWM) and barley (BM) malts

Parameters	SM45	SM70	CWM	BM
Moisture [% w/w]	4.8±0.1^{a}	4.3±0.1^{b}	3.7±0.1^{c}	4.1±0.2^{b}
Color [EBC unit]	3.0±0.7^{a}	3.3±0.2^{a}	4.0±0.3^{a}	11.2±0.3^{b}
Extract [%]	81.2±1.7^{a}	81.7±0.9^{a}	81.4±0.7^{a}	80.5±0.6^{a}
Soluble Proteins [% db]	3.8±0.2^{a}	3.6±0.3^{a}	4.3±0.3^{a}	4.2±0.5^{a}
Kolbach Index [%]	40.3	38.1	46.7	38,2
FAN [mg/100g]	85.2±2.1^{b}	72.3±0.8^{c}	100.0±4.2^{a}	106.5±2.6^{a}
Starch [% db]	57.3±0.8^{a}	60.5±1.4^{a}	57.0±1.8^{a}	n.a.
WEAX [% db]	1.05±0.02^{a}	1.05±0.03^{a}	0.71±0.01^{b}	0.35±0.01^{c}
A/X	0.74	0.75	0.75	0.62
BG [% db]	0.05±0.01^{a}	0.05±0.01^{a}	0.06±0.01^{a}	2.43±0.04^{b}

FAN = Free Amino Nitrogen; WEAX = Water Extractable Arabinoxylans; A/X = arabinose/xylose ratio. All values are expressed as means ± standard deviation (n = 3); values in the same row followed by different letter are statistically different ($p \leq 0.05$).

Table III. Main enzyme activities detected for durum (SM40 and SM70), common (CWM) and barley (BM) malts

Enzyme activities	**SM45**	**SM70**	**CWM**	**BM**
β-glucanase [U/g]	14.9±0.1^{b}	11.2±0.2^{c}	1.3±0.1^{d}	31.1±0.1^{a}
Endo-xylanase [XU/g]	0.76±0.01^{a}	0.76±0.01^{a}	0.11±0.01^{c}	0.30±0.01^{b}
α-amylase [CU/g]	149.9±0.8^{b}	120.9±1.31^{c}	54.7±0.3^{d}	177.0±2.7^{a}
β-amylase [BU/g]	58.2±0.2^{a}	50.5±0.3^{b}	34.7±0.4^{c}	24.5±0.1^{d}

All values are expressed as means ± standard deviation (n = 3); values in the same row followed by different letter are statistically different (p ≤ 0.05).

Table IV. Characteristics of EBC congress worts brewed with 60% of barley malt (BM) and 40% of different wheat malts, respectively SM45, SM70 and CWM

Parameters	**SM45**	**SM70**	**CWM**	**BM**
Color [EBC unit]	8.9±0.1^{c}	10.8±0.1^{b}	11.3±0.1^{a}	11.2±0.3^{b}
Extract [% db]	82.2±0.6^{b}	82.7±0.4^{b}	83.2±0.3^{a}	80.5±0.6^{c}
FAN [mg/100g]	115.3±2.2^{b}	110.2±2.4^{c}	122.4±2.1^{a}	106.5±2.6^{c}
Saccharification time [min]	5.0	5.0	10.0	5.0
pH	6.04±0.01	6.01±0.01	6.03±0.11	5.99±0.01
WAX [mg/100g]	592.6±4.0^{a}	572.4±2.3^{b}	588.6±5.7^{a}	429.2±0.6^{c}
A/X	0.53	0.57	0.54	0.56
WBG [mg/100g]	151.5±0.6^{d}	177.8±4.5^{c}	230.4±2.2^{b}	280.5±3.7^{a}
Viscosity [mPa.s]	1.47±0.01^{c}	1.51±0.01^{b}	1.60±0.01^{a}	1.51±0.01^{b}

All values are expressed as means ± standard deviation (n = 3); values in the same row followed by different letter are statistically different ($p \leq 0.05$).

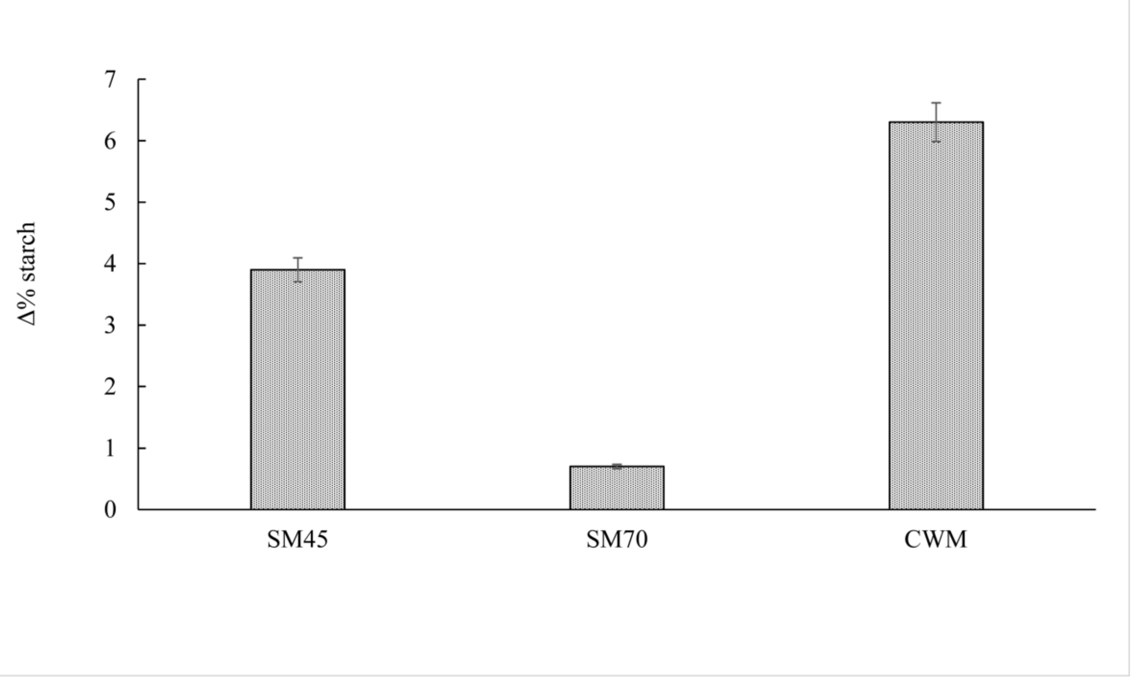

Figure 1. Starch content decrease after malting process detected for SM45, SM70 and CWM.

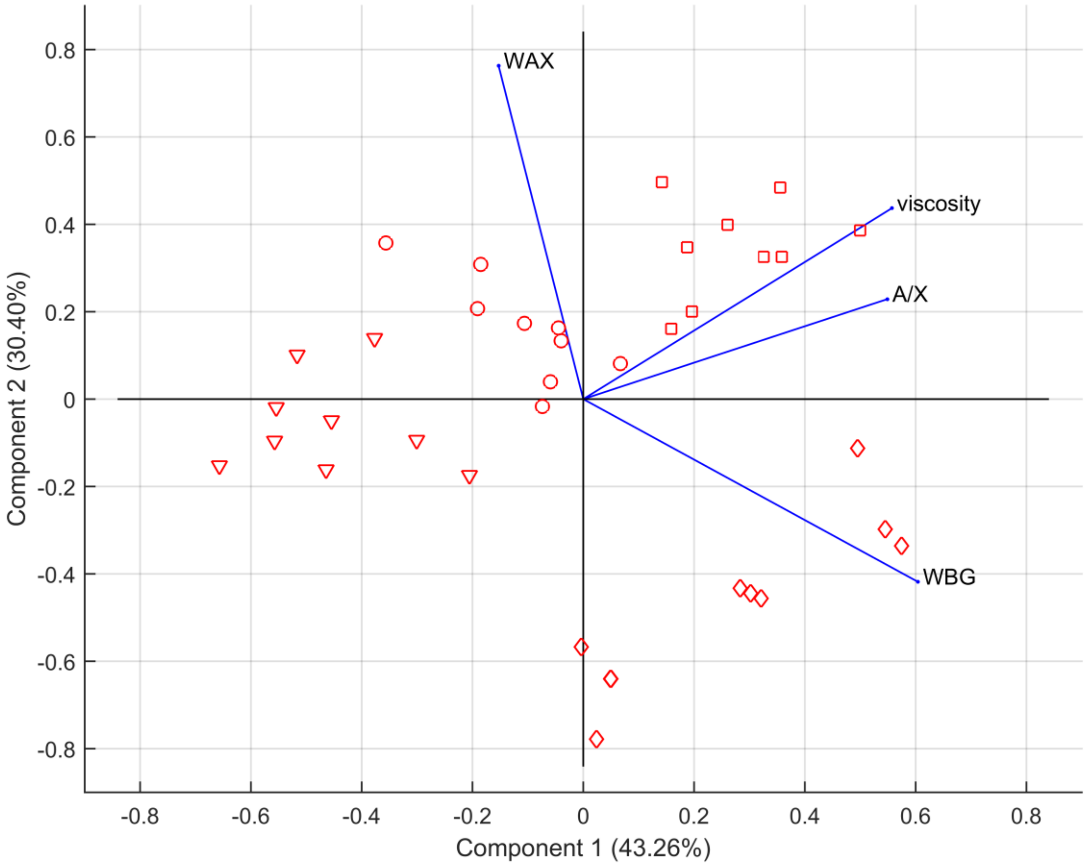

Figure 2. Grist blend (◊ $BM_{100\%}$, □ $CWM_{40\%}$, ○ $SM70_{40\%}$, ∇ $SM45_{40\%}$) x NSP and viscosity biplot from PCA.

Chapter 5

Screening of Durum Wheat Landraces (*Triticum Turgidum Subsp. Durum*) for the Malting Suitability

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Abstract

Durum (T. turgidum subsp. durum) wheat production worldwide is substantially less than that of common wheat (Triticum aestivum) mainly due to the relatively limited end-user. In this study, sixteen old durum wheat landraces were malted at micro scale, and quality parameters of the resulting malts were measured. Furthermore, the endo-β-glucanases, the endo-1,4-β-D-xylanase α and β amylases activities were also measured. The malt quality parameters were in the range 78.2-85.9% for the extract, 72.9-80.9% for the fermentability, 3-5 EBC units for the color, 0.49-0.79% dm for water-extractable arabinoxylans and 0.043-0.059% dm for the β-glucans. The wort viscosity (1.53-1.92 mPa.s) was negatively correlated with the endo-1,4-β-D-xylanase and positively correlated with endo-β-glucanases, while no correlations were found with arabinoxylan and betaglucan wort content.

Keywords:

Durum wheat, wheat malt, malting, arabinoxylans, β-glucans, wort viscosity.

5.1 Introduction

Wheat is one of the major staple food consumed worldwide. According to the Food and Agriculture Organization (FAO), the global wheat production in 2016 reach 724 million of tonnes (Belhassen, Calpe & Abbassian, 2017). Common wheats (*Triticum aestivum* L.) represent the widespread species while durum wheats (*Triticum turgidum,* subsp *durum* Desf.) are mainly cultivated in the Mediterranean area. In 2016, over 2.7 million hectares were cultivated with durum wheat in the European Union (EU, 28) and the production accounted for about 9.5 million of tonnes (Eurostat, 2017). Italy represents the principal EU producer with more than 5.0 million of tonnes of durum wheat harvested in 2016 (Eurostat, 2017; Istat, 2017). In the same year, Apulia and Sicily were the leader regions producing together over the 40 % of the national production (Istat, 2017).

During the 20th century, the durum wheat breeding programs aimed to the improvement of the agronomic performances and the technological quality. New durum wheat landraces with improved gluten quality led to better technological performance but also higher allergenic potential (De Santis et al., 2017). The local traditional landraces, well adapted to specific environment but less suitable for industrial purposes, have been gradually replaced by high yielding varieties leading to strong reduction of the biodiversity. The old durum wheats showed wide adaptability and rusticity, which are useful characteristics for the cultivation in the internal and rural areas with reduced rainfall as the southern Mediterranean regions. The recent EU agricultural policy, promoting the improvement of soil and the low inputs agronomic management, it was a driving force for the reintroduction of the wheat landraces in marginal and rural areas enhancing biodiversity.

Several studies were carried out for the assessment of the effects of genotype, environmental and agronomic conditions on grain quality characteristics and nutraceutical composition for the old and modern durum wheats (Fois et al., 2011; Rascio et al., 2015; Mangini et al., 2016). Others researchers investigated how old landraces show different phenolic pattern and, unlike modern, higher dietary fibre and antioxidant levels (Dinelli et al., 2009 and 2013). The rheological characteristic of the semolina and the sensorial profiles for bread and pasta made processing old durum wheat landraces were also extensively studied (Gallo et al., 2010; Padalino et al., 2014). Only few previous studies report for durum wheat the brewing performances, when it was used as unmalted cereal (Mascia et al., 2016). Moreover, some Indian durum wheat lines were tested for the malting characteristics however no data are available for malted Italian durum wheat landraces (Suhasini et al., 2004). In traditional beer making countries, such as Germany, common wheat is used as a source of fermentable extract to beer production. In the malting process the hydrolysis of the cereal endosperm occurs by specific enzymes, degrading proteins, starch and non-starch polysaccharides (NSP).

The protein level play a key role in malting cereals, an increasing protein content in wheat led to low proteins solubility and Kolbach Index (Jin et al., 2008). In malting wheat, the negative effect of high protein values can be overcome facilitating the degradation process by extending the germination phase (Jin et al., 2008). On the contrary, with an extensive protein degradation and high Kolbach index values, strong respiration rates and increasing malting losses were reported (Jin et al., 2012). Furthermore, the protein degradation affects the availability and the activities of the polysaccharide-degrading enzyme and the wort quality attributes (Jin et al., 2014). Taking into account that the extract yield represents a key indicator in brewing, relatively high starch content and low protein values were the required characteristics for wheat landraces suitable for malting (Jin et al., 2011). A starch content of about 50-75% is recommended for malting wheat (Jin et al., 2008). With regard to NSP, wheat arabinoxylans can reach about 7% of the whole kernel weight and represent the main constituents of the endosperm cell walls (Faltermaier et al., 2014). The structure of the wheat arabinoxylans consists of a linear backbone of β-D-xylopyranose and α-L-arabinofuranose side-chain at O-3 or both at O-2 and O-3 on the xylose backbone. The arabinoxylan polymerization degree affects their physicochemical properties such as solubility and viscosity (Krahl et al., 2009). In wheat, the β-glucan levels are lower than in other cereals and their regular structure, consisting mainly of trisaccharide units, makes it less water soluble (Cui et al., 2000). The microstructural changes of proteins, starch and NSP were observed and reported during the wheat malting process (Faltermaier et al., 2015). In brewing process, high-molecular-weight NSP may cause reduced extraction efficiency, high viscosity, poor filterability and haze formation in worts and beers (Debyser et al., 1997 and 1998; Lu and Li, 2006). Because of their high arabinoxylan content these problems are marked when wheat or wheat malt were used (Lu and Li, 2006).

In a recent review of the use of common wheat as a brewing cereal, Faltermaier and other authors (2014) pointed out the increasing interest to screen wheat landraces for malting and brewing purposes, taking into account that lower protein and viscosity values are suitable characteristics.

Based on the above considerations, the present study aimed to evaluate the malt quality traits of different durum wheat genotype. To reach this goal, 16 old durum wheat landraces were malted following the same malting regime, using a common wheat as a control test. The malting quality parameters, the protein and starch degradation processes, the activity of starch- and NSP-degrading enzymes were studied for the first time on old durum wheat landraces. Considering the effects of NSP on wort viscosity, arabinoxylans and β-glucans level were measured for wheat grains and for their malts and worts.

5.2 Materials and Methos

Wheat Grains. In the 2014-2015 season, 16 old durum wheat landraces (Bidì, Capeiti, Chiattulidda, Farro Lungo, Francesa, Gioia, Giustalisa, Inglesa, Martinella, Realforte, Regina, Russello, Trentino, Tripolino, Tumminia and Urria) and a common wheat (Vivant) used as a control test, were grown in Italy at the “Stazione Consorziale Sperimentale di Granicoltura per la Sicilia” farm in Caltagirone (Lat. 37°14’ Long. 14°30’, 350 m a.s.l, sandy clay soil). The same agro-technical protocols was applied to all landraces, cropped in two field plots of 100 m^2 each. The sowing, 350 viable seed for m^2, was carried out in December 2014 supplying 40 kg ha^{-1} of N and 90 kg ha^{-1} P_2O_5.

Wheat analysis. The wheat analyses were carried out in triplicate according to Analytica EBC (2007). In particular, the grain moisture (%) was determined by EBC method 3.2; the germination energy (GE, %) by EBC method 3.6.2; the thousand corn weight (TCW, g of dm) by EBC method

3.4; the total protein as total nitrogen multiplied by 5.7 with EBC method 3.3.1. Megazyme assay kit (Megazyme International Ireland) was used for total starch content (% dm) determination following AOAC (2005) method 996.11.

Malting Procedure. Malting tests were performed in triplicate using a micromalting plant (Albert Maltings, Ruisbroek, Belgium). Samples were cleaned to remove glumes and husks or, if present, external contaminants by manually sieve and air flow. For each landrace, 800 g of grains were steeped in water at 15° C for 5 h followed by 8 h of air-rest and further 4 h in water reaching a steeping out moisture of 42%. The samples were germinated 120 h at 15 °C and 95% of RH. The germinating grains were carefully dried and then kilned in 34 hours as follow: 3 h at 55 °C, 12 h at 60 °C, 10 h at 65 °C, 5 h at 70 °C and 4 h at 75 °C. Roots and acrospires were removed from the malted wheats at the end of the process.

Malt analysis. *Wheat Malt Quality*. The Analytica-EBC (2007) methods were used for malt analysis: malt moisture (%) was measured by EBC method 4.2, thousand corn weight (TCW, g of dm) by EBC method 4.4, total nitrogen (TN, % dm) by EBC method 4.3.1, soluble nitrogen (SN, % dm) by EBC method 4.9 and malt color by EBC method 4.7.1. Total and soluble proteins (% dm) were calculated as reported above (2.2 Wheat analysis) and the Kolbach index (%) as SN to TN ratio.

The degree of the overall endosperm modification was assessed by friabilimeter, which separated samples mechanically into its hard and friable parts. The friable malt parts pass through the drum sieve, while the wholly and partly unmodified grains remain inside the friabilimeter drum and were further sieved during 60 seconds to pass at 2.2 mm sieve. The grains fraction larger then 3/4 of the malt corn size were considered as wholly unmodified grains (WUG). The rest of the fraction left on the 2.2 mm sieve represents the partly unmodified grains (PUG). The malt friability (%), wholly unmodified grains (WUG, %) or partly unmodified grains (PUG, %) were estimated by friabilimeter according to EBC method 4.15. Megazyme assay kit (Megazyme International Ireland) was used for total starch content (% dm) determination following AOAC (2005) method 996.11.

The degraded starch (Δ starch % dm) during malting process was calculated for each landrace as difference between the average wheat (W) and malt (M) starch content (Δ starch % = W – M) according to Jin et al. (2011).

β-Glucan Content. β-glucan valueswere determined for wheats (BG), malts (MBG) and congress worts (WBG) via Megazyme assay kit (Megazyme International Ireland), following, respectively, EBC methods 3.10.1., 4.16.1 and 8.13.1.

Total, Water-Extractable and Wort Arabinoxylan Content. Total arabinoxylans (AX), water extractable arabinoxylans (WEAX) and wort arabinoxylans(WAX) were determined by gas-liquid Chromatography (ThermoQuest, model Trace 2000 series, Rodano, Italy) using a flame ionization detector and a RTX-225 column (30 m, 0.25 mm ID, 0.2 µm film thickness). According to Debyser et al. (1997), malt flour was heated at 130 °C during 5 h to eliminate enzyme activities before carrying out the WEAX extraction. The water suspensions, prepared by stirring 2 g of pre-heated samples (1/10 w/v) at 30 °C for 2 hours, were hydrolyzed after centrifugation (3000*g*, 15 min.). AX, WEAX and WAX hydrolyses were performed by 2.0 M trifluoroacetic acid (120 minutes at 110 °C). The alditol acetates were prepared following the method proposed by Englyst and Cummings (1984). The separation of the alditol acetates was carried out at 225 °C, the carrier gas was He (flow rate 1.5 mL/min) and the internal standard was β-D-allose.

Enzyme Activities. The *endo*-β-glucanases activities were measured by β-glucazyme tablets (Megazyme International Ireland). Xylazyme tablets (Megazyme International Ireland) were used for the determination of the *endo*-1,4-β-D-xylanase activity. The malt amylase assay kit (Megazyme International Ireland) was used to quantify α and β amylases in malt flours. All the enzyme activities are showed as units per grams of dry matter (U/g). One U of activity is defined as the amount of enzyme required to release one micromole of reducing-sugar equivalents per minute under the defined assay conditions.

Congress wort analyses. Extract (% dm) from wheat malts was measured by EBC method 4.5.1, fermentability (%) by EBC method 4.11.1, pH by EBC method 4.5.1, saccharification time (min) by by EBC method 4.5.1 and free amino nitrogen (FAN, mg 100 g^{-1} dm) by EBC method 4.10. The determination of the wort viscosity (mPa.s) was carried out using a falling ball micro viscometer (Anton Paar GmbH, Graz, Austria) following EBC method 4.8.

Statistical Analyses. For each parameter, the data reported as mean of three technological and three analytical replications. One-way analysis of variance (ANOVA) and principal component analysis (PCA) were carried out with MATLAB software (MathWorks, version 8.5.0). Pearson correlation coefficients were obtained using SPSS software (IBM, version 22).

5.3 Results and Discussion

Wheat Grains analyses. The quality traits assessed for the wheat grains are reported in table 1. The post-harvest moisture values observed were in the range, 9.02-10.57 %, favourable to storage at low temperature and RH. Aiming to test the percentage of grains, which can be expected to germinate in malting, the GE was evaluated and the results were showed in table 1. The landraces showed GE values suitable to malting and, except Farro Lungo (95.8%), the other samples were in the range 97-99%. The GE values observed in our tests were similar to that reported by other researchers for wheat (Jin et al., 2008 and 2011). The TCW values reported in table 1 show high variability. The landraces Farro Lungo, Bidì, Russello and Gioia showed a TCW value ranged from 59.2 g dm to 47.5 g dm, comparable to that reported in other research carried out for durum wheats (De Santis et al., 2017), but higher than other samples and literature evidence for malting wheats (Jin et al., 2008 and 2011; Boros et al., 2014).

In malting cereals, proteins represent a key attribute for malting cereals affecting yeast nutrition, fermentation, foam stability and beer taste. Grain protein content are landrace dependent and inside the same landrace the agronomical management (macro and micro nutrient inputs), environment and harvest year affect the protein availability. The protein content values ranged from 8.11 % dm for Tripolino to 12.63 % dm for Tumminia. In comparison to other research carried out for malting wheats (Jin et al., 2011; Xie et al., 2014), the observed proteins content were lower but still suitable to malting and brewing purposes (Briggs, 1998). The starch content values was in the range 59.7-

67.2 % dm, Tumminia showed the lowest content confirming an inverse relationship between protein and starch content. The observed starch content was comparable to the literature for wheat (Jin et al., 2011).

Wheat malt quality. The main wheat malt characteristics are reported in table 2. After the malting process the moisture values were comprised between 3.3 to 5.3 % w/w, respectively for Capeiti and Gioia landraces. During the malting process, a weight loss occurs due to the respiration in germination and to roots and acrospires removal. This behaviour can be observed through the reduction of the TCW, the extent of which was landrace dependent. The average weight reduction detected for our tests was about 7% of the original weight. Tripolino (13.7%) and Gioia (11.4%) show the highest weights drop, while Urria (2.9%) and Bidì (2.8%) were the landraces showing the lowest weight losses.

The different wheat malts show protein content ranging from 7.0% dm in Tripolino, to 10.9% dm in Tumminia. Common wheat (Vivant) showed 10.3% dm of total protein content and the highest level for soluble protein (4.9 % dm) which was statistically different ($p \leq 0.05$) from all the others samples. In agreement with those reported by other researchers, high protein content did not result in higher values of soluble protein (Jin et al., 2008). The lowest values for soluble proteins were detected for Farro Lungo, Bidì and Capeiti (table 2).

During the malting process the wheat starch content decreases due to the enzymatic hydrolysis of the starch to soluble sugars. The starch values detected for wheat malts were in the range 42.6-63.5 % dm, respectively for Urria and Bidì and the average level was comparable to the values found in literature for wheat malt starch (Jin et al., 2011). The malts color are reported in table 2 and were comprised in the range 3.0-5.0 EBC units. The common wheat malt control test was the darkest landrace, probably due to the Maillard reaction related to the higher soluble protein content, whilst all the wheat malts were paler compared to the data available in literature (Jin et al., 2014; Xie et al., 2014; Guo et al., 2014).

The trend for protein (Kolbach Index) and starch (Δ% starch) degradation are showed in Figure 1. During the malting process, insoluble storage proteins are hydrolysed and further degraded by proteolytic enzymes to polypeptides and amino acids. Moreover, proteins are synthesized during germination and Kolbach Index increases until reaching the balance between protein degradation and synthesis. Different authors reported on the behaviour of foam stability in relationship to protein degradation and in particular low protein degradation lead to a better foam quality and a low foam stability with high Kolbach Index (Evans et al., 1999 and 2002).

High heterogeneity was observed among landraces, the Kolbach Index ranged from 35.5%- 51.5% in Chiattulidda and in Tripolino respectively with comparable values discussed in literature for common wheats (Jin et al., 2012). Excluding few landraces showing greater protein degradation the other samples show the protein degradation index comparable to the typical range (35-45%) proposed for wheat malt (Faltermaier et al., 2015).

The reduction of the starch content during malting is due to the action of the starch hydrolysing enzymes and calculated as Δ% starch as presented in figure 1. The soluble sugars from starch degradation were partially consumed by the wheat germination, the residual sugars are removed by ethanol before starch analysis according with AOAC method (2005). The Δ% starch observed for durum and common wheat malts ranged from 3.3 - 24.3 % dm, respectively for Bidì and Urria. The landraces Chiattulidda, Regina, Realforte, Russello and Urria showed over 15% dm of reduction in starch content, greater than the values found for common wheats in malting tests carried out by other researchers (Jin et al., 2011).

The results of the friability tests were shown in table 3. The degree of malt modification shows high heterogeneity among wheat landraces and the friability ranged from 28.3% - 80.0%, respectively for Chiattulidda and Common wheat malts.

The durum wheat landraces showing the highest friability values were Tripolino (53.9%), Trentino (50.3%) and Martinella (48.8%). The friability was comparable to the values reported to the literature for wheat malt[33] and it was lower than for barley malt (Edney and Mather, 2004). The presence of glassy endosperms was defined by WUG values reported in table 3. The wheat landraces with the higher percentage of unmodified corns were Urria, Tumminia and Chiattulidda showing respectively WUG values of 14.8%, 13.2% and 8.2%. The landraces Common and Martinella did not revealed glassy corns with WUG values equal to 0.0%. The trend observed for PUG was in the range 0.0-30.0% with Tumminia, Chiattulidda and Farro Lungo showing the highest values. The lowest malt modification and the highest values of unmodified glassy corns were probably due to the presence of vitreous endosperms in durum wheat landraces (Edney and Mather, 2004; Samson et al., 2005; Ondrejovič et al., 2014).

Principal component analysis (PCA) was carried out to evaluate the influences of genotype on the endosperm modification and the extent of the main degradation processes. The PCA was performed to summarize the difference between genotypes considering Friability, WUG, PUG, K.I. and Δ starch as variables. Two principal components (PC) were selected, explaining 78.7% of the variances, respectively 60.5% from the PC1 and 18.2% from the PC2. The biplot (figure 2), show the sample scores and the loading resulting from the PCA.

The main differences were observed for the PC1 that spreads the sample scores according to the endosperm modification degree. The relative position of the sample scores on the positive side of the PC1 reflect the presence of under modified and glassy endosperms with a substantially reduced proteins degradation (K.I.). The genotypes plotted on the negative side of the PC1 were the samples with increasing endosperm modification that led for some samples to an excessive proteins degradation. The PC2 separates the sample scores according to the extent of starch and protein degradation observed in malting process. The genotype plotted in the positive side of the PC2 show the strongest intensity, both for starch and for proteins degradation processes. The landraces Urria, Russello, Regina and Chiattulidda, plotted on the first quadrant, were characterized by high level of glassy endosperm with a weak protein degradation and a strong reduction in starch content. Farro Lungo, Capeiti and Tumminia were the landraces less modified with a relevant presence of under modified endosperms and a reduced degradation for protein and starch. Other samples such as

Tripolino, Common and Trentino also if show relevant difference for the degree of endosperm modification which impact on friability, were characterized by an excessive degradation for proteins (K.I. > 45%), while the other landraces have had intermediate intensity of endosperm modification and degradation processes.

Non-starch polysaccharides (NSP). With regard to NSP, wheat arabinoxylans represent the main constituents of the endosperm cell walls whilst β-glucans are concentrated in the aleuronic layer with lower value than in other cereals (Saulnier et al., 2007). The regular structure of the wheat β-glucans, consisting mainly of trisaccharide units, makes it less water-soluble than β-glucans from other cereals (Cui et al., 2000). Table 4 show wheat and wheat malt β-glucans trend. In wheat, the β-glucan values ranged from 0.13 – 0.25 % dm in Farro lungo and Tumminia. The common wheat shows a value comparable to Farro lungo and more in general the β-glucan availability was limited for all the wheat samples. The β-glucan values observed for the whole wheat were lower than the values reported by other researchers (Li et al., 2006; Marconi et al., 2011).

During the malting process, the β-glucans concentration decreases under the action of the degrading enzymes and for the malts residual β-glucans were in the range 0.043-0.059 % dm (table 4). Some landraces, such as Common and Farro lungo, had the β-glucan values with reverse trend compared to that observed for wheat β-glucans (table 4). Despite the lower content found in wheat for the above-mentioned landraces, the β-glucans measured in malts were higher than in other samples. After malting, except for Common, Gioia and Farro lungo, the other landraces show a level lower than 0.05 % dm.

Considering their higher concentration, arabinoxylans represent the most important NSP in wheats. The wheat arabinoxylans structure consists of a linear backbone of β-D-xylopyranose units linked through 1,4 glycosidic linkages and α-L-arabinofuranose side-chain at O-3 or both at O-2 and O-3 on the xylose backbone. The wheat genotypes and the grain tissues influence the amount and structures of the arabinoxylans. The AX values measured for the tested wheat show high variability and were in the range 2.9-5.6 % dm (table 4). Regina landrace shows the highest AX content and was the only sample with a level over the 5 % dm, while Gioia had the lowest AX availability. These last samples show significant differences ($p \leq 0.05$) among other wheat samples. The AX content of the common wheat (3.9 % dm) was comparable with the other durum wheats in our study and all the samples show average low AX content such as reported in literature for modern durum wheat landraces (Ciccoritti et al., 2011).

The water extractable part of the wheat malt arabinoxylans (WEAX) ranged from 0.49-0.79 % dm (table 4). The detected amounts for all samples were lower than the amounts revealed in other research (Li et al., 2004). The common wheat shows the highest level (0.79 % dm) and a similar trend was observed for Trentino, Tripolino and Regina. The lower water extractability was observed for Bidì (0.49 % dm) and together with Gioia, Giustalisa, Francesa, Chiattulidda and Tumminia show an average WEAX level lower than 0.60 % dm. In accordance with other researchers (Guo et al., 2014), a high portion of the wheat malt arabinoxylans were found to be water insoluble and no correlations are found between WEAX and the wort viscosity (Faltermaier et al., 2014).

Table 4 shows the trend of WBG and WAX in the mashed wheat malts. As previously mentioned β-glucans in wheat malt are available in small amount and WBG was comprised between 50.4 mg l^{-1} in Chiattulidda to 70.1 mg l^{-1} in Common wheat. Limited to durum wheat malts, only the landraces Gioia, Bidì and Farro lungo show WBG concentration higher than 60.0 mg l^{-1}. The WBG concentration observed for wheat malts was lower than the typical level reported for barley and wheat malts (Li et al., 2004). Differently from WBG, high variability was observed for WAX, which ranged from 584.7-1140.5 mg l^{-1}, respectively for Giustalisa and Common. The landraces Capeiti and Trentino were the only durum wheat malts showing WAX level higher than 1000.0 mg l^{-1} and all the samples show WAX concentration lower than the values reported in the literature for barley and wheat malts (Li et al., 2004).

The arabinose to xylose ratio is an important parameter indicating the degree of substitution of the arabinose residues on the xylan backbone. Table 4 shows the behaviour of A/X ratio in the different wheat landraces for total AX, WEAX and WAX.

The A/X was in the range 0.62-0.86 for total AX, 0.66-0.87 for the WEAX and 0.52-0.64 for the WAX. The common wheat shows the lowest degree of arabinose substitution, both for AX and WEAX, while in WAX the A/X was comparable with the other wheat samples. The landraces Farro Lungo and Realforte show the highest values of arabinose substitution respectively for total AX and WEAX. The landraces Bidì, Capeiti, Giustalisa, Martinella and Realforte show higher arabinose substitution in WEAX than in total AX, as reported by literature (Li et al., 2004).

More in general, for all the samples the A/X ratios were comparable between total AX and WEAX, while in A/X ratios observed for WAX were lower than in the other fractions. This fact was probably due to the action of the arabinoxylan debranching enzymes during mashing. No correlations were found between the wort viscosity and the different fractions for β-glucans and arabinoxylans, as well as for the A/X ratios.

Enzyme Activities. In malting process, starting from the cell walls, specific groups of enzymes attack the endosperm compounds. BG and AX mainly represent the NSP that occur in cereal cell walls. The high molecular weight 1-3, 1-4-β-D-glucans are solubilised from the cell walls and degraded by endo-β-glucanases such as endo-1,3-β-glucanase, endo-1,3:1,4-β-glucanase and endo-1,4-β-glucanase, during malting and brewing processes. The molecular weight reduction of the BG polymers impact on the wort viscosity by decreasing the average level (Debyser et al., 1998). Table 5 shows the values for endo-β-glucanase activities in the wheat malts tested.

The wheat genotypes show significant difference between samples ranging from 1.43-18.99 U g^{-1} of endo-β-glucanase activity. The results show the maximum value of enzyme activity in Common wheat malt. Significant differences ($p \leq 0.05$) among durum wheat samples were found. Tumminia, Trentino and Realforte had the highest endo-β-glucanase activity, respectively 5.4, 4.6 and 4.5 U g^{-1} such as reported in literature for common wheat malt (Jin et al., 2014). Low values of endo-β-glucanase activity (3 U g^{-1}) was found in ungerminated common wheat (Jin et al., 2014). These endo-enzymes were inactivated after 15 minutes at 50 °C, whilst the β-glucan solubilases were still active above this temperature. The high molecular weight BG released during the last part of mashing are no longer degraded (Bamforth and Martin, 1981; Jin et al., 2004). The presence of high-molecular-weight NSP in malts can result in reduction of extraction efficiency and high viscosity with consequent poor filterability and haze formation in worts and beers (Debyser et al., 1997 and 1998). Because of their high arabinoxylan content these problems were marked when wheat or wheat malt were used as adjunct (Lu and Li, 2006).

During malting and brewing, several enzymes are involved in arabinoxylans degradation such as endo-1,4-β-D-xylanase, β-D-xylosidase and α-L-arabinofuranosidase. Under the action of the endo-1,4-β-D-xylanases, high molecular weight arabinoxylans are degraded into xylo-oligosaccharides further degraded by β-D-xylosidases releasing xylose monomers and α-L arabinofuranosisases acts to remove arabinose residues from the xylan backbone. The endo-xylanase activity observed in malts and the arabinoxylan concentration in the resulting worts were found to be positively related (Debyser et al., 1997).

The depolymerisation operated by endo-1,4-β-D-xylanase affect the physiochemical properties of arabinoxylans such as solubility and viscosity (Krahl et al., 2009; Dornez et al., 2009). The endo-xylanase activity found (table 5) ranged from 0.21-0.43 U g^{-1}. Significant differences ($p \leq 0.05$) were observed for Common that show the lowest endo-xylanase activity (table 5) and the highest wort viscosity (table 4). Realforte, Regina, Chiattulidda and Tripolino registered an activity about two time higher than common wheat malt. The enzymes involved in hydrolysis and degradation of arabinoxylans are produced at the end of the germination process (Banik et al., 1997). The endoxylanase activity detected after 72 h of germination was two-time higher than in finished malt (Li et al., 2004). The arabinoxylans hydrolysis from the endosperm cell walls increase the availability of the starch facilitating amylase activities. Different hydrolyzing enzymes attack starch granules producing fermentable sugars and dextrins. The malt amylases, presented in table 5, play a key role in mashing. The β-amylase cuts alternate α-1,4 linkages from the non-reducing end of the starch molecule. This enzyme is present in free, insoluble and latent form in unmalted grains (Evans et al., 1997). The insoluble and latent forms of β-amylases, bound via disulphide bridges to protein compounds, are released during the germination (Faltermaier et al., 2014). Tumminia shows the highest β-amylase level (43.9 BU g^{-1}), the activities in Trentino, Tripolino and Urria were significantly lower (<30 BU g^{-1}) and no correlations were found between β-amylase and the starch hydrolysis during malting. The activity ranged from 28.7-43.9 BU g^{-1}, comparable enzyme activities were reported in the literature for wheat malts (Jin et al., 2011).

Differently from the β-amylase, α-amylase is synthesized in the aleurone cells during the germination process (Falermaier et al., 2014). The α-amylase cuts the α-1,4 linkages from the inside, degrading amylose and amylopectin to dextrins. In our samples, α-amylase shows high variability (46.6-130.7 CU g-1). Tumminia and Regina were the top landraces showing significantly highest α-amylase activity ($p \leq 0.05$). Other samples, such as Farro Lungo and Chiattulidda show poor α-amylase activity that could also affect extract and saccharification. The reduced amylase activity observed for Farro Lungo was probably due to the higher corn size. In fact, it is know that in large sized corns the release and synthesis of the enzymes occurs with slow rate according to the longer time required for germination (Briggs, 1998). This behavior appears to be confirmed in Farro Lungo (TCW 54.9 g dm), as well as in Bidì (TCW 47.9 g dm), showing reduced starch hydrolysis associated with lower amylase activity. Excluding these lasts two landraces, the values of the other samples were higher than the amylase activity reported by other researchers for wheat malts (Faltermaier et al., 2014) and comparable to barley malt (Toffoli et al., 2003; Hattingh et al., 2013).

Congress wort characteristics. The characteristics of the congress worts are shown in table 6. The extract (%) is one of the most important malt parameters to evaluate for the suitability in brewing and is higher for wheat than barley malt because of the absence of husks. The extract values detected for our samples ranged from 78.2% in Chiattulidda to 85.9% in Martinella and similar values are showed in the relevant literature for wheat malt (Jin et al., 2011 and 2014). Other landraces such as Tripolino, Gioia, Bidì and Giustalisa show extract values over 84%, moreover for 9 genotypes we observed more than 83% of extract. Taking into account the differences observed for the starch degrading enzymes (section 3.5), no correlations were found with the resulting extract and unexpectedly, acceptable values were recovered from the samples that have been showing the lowest α-amylase activity (Farro Lungo, Chiattulidda, Ralforte and Bidì).

The fermentability (%) represents the available fermentable sugars extracted in mashing and is considered as a relevant malt characteristic for brewing suitability. Typical values of the fermentable sugars in wheat malt are in the range 76-82%, while for barley malt this is about 80% (Kunze, 2004).

The fermentability values found for our tests are reported in table 6 and range by 72.9% in Farro Lungo to 82.5% in Martinella. The behaviour was comparable between samples and the slight differences were probably due to the occurrence in some wheat genotypes of different values of starch degrading enzymes, such as limit-dextrinase and α-glucosidase, affecting the availability of the fermentable sugars (Di Ghionno et al., 2017).

The free amino nitrogen (FAN), that represent the amount of free amino acids, ammonia and small peptides, show different trends among samples and ranged from 130.12 mg l^{-1} in Russello, to 74.61 mg l^{-1} in Regina. The FAN levels measured for Russello, control test, Inglesa, Trentino, Gioia and Realforte were over 100 mg l^{-1}. Furthermore, the FAN and soluble nitrogen ratio of our samples was comparable to the ratio calculated to the data reported by literature for wheat malt (Jin et al., 2008 and 2014).

The wort pH measured for the wheat malt samples were higher than the optimal range for β - (5.4-5.6) and α - (5.6-5.8) amylases and was in the range 5.97-6.33. The Common wheat genotype shows the lowest pH level and for the other samples, the pH values were up to 6.0. It is well know that the pH influences the enzyme activities, affecting hydrolysis and degradation of the main malt extractable compounds (Lehninger et al., 1993). In particular, the effects of high pH values became evident in terms of time required for the starch saccharification. For our samples the saccharification time (min) range by 10 minutes in Common and Tumminia, to 25 min in Farro Lungo, Bidì and Regina (data not shown) and similar behaviour is reported in the literature for the wheat malt (Jin et al., 2011 and 2012).

The wort viscosity, due to the effects on filtration rate, is an important parameter to evaluate the suitability of durum wheat for malting and brewing. It is well know that the major contribution to the wort viscosity is due to the NSP molecular weight and their concentration, these parameters affect also filterability and haze formation in worts and beers (Debyser et al., 1997 and 1998; Lu and Li, 2006).

The viscosity observed in congress wort shows high heterogeneity among the samples (table 6). The highest value was found for reference wheat (1.92 mPa.s).The durum wheat malts show values ranged from 1.56-1.84 mPa.s respectively for Capeiti and Russello. In all samples except Common and Russello, the viscosities were lower than the recommended value of 1.8 mPa.s (Faltermaier et al., 2014).The viscosity values were comparable to those reported in literature for common wheat malt (Jin et al., 2012 and 2014).

Table 7 shows the correlations between the degradative enzymes and quality indices of the wheat malts and worts. β-amylase shows a positive correlation with the protein content while α-amylase appear not correlated with the selected quality indices. Among the NSP degrading enzymes endo-β-glucanase shows positive correlation with the level of soluble proteins, malt friability, as well as wort viscosity (table 7). The endo-1,4-β-D-xylanase, differently from endo-β-glucanase shows a negative correlation (-0.602, $p \leq 0.05$) with the viscosity of the wort and no correlation was found with the other quality traits. The wheat malt soluble proteins were positively correlated to friability, Kolbach index and wort viscosity. The extract values show negative correlations with the decrease in starch content (Δ starch), the amount of glassy corns (WUG) and the malt protein content. The friability appears to be positively correlated with the index of protein modification (K.I.) and negatively correlated to the amount of glassy unmodified corns (WUG).

5.4 Conclusions

The results obtained in this study showed that the durum wheats have optimal germination energy, showing on average lower protein, non-starch polysaccharides availability and comparable starch levels to the brewing wheat varieties. The malted durum wheats showed high variability in degradation intensity for protein, starch and in general for the overall endosperm modification with lower protein solubility and paler color than the control test. The endo-glucanase levels were lower in durum wheat malts compared to the activities observed in our common wheat malt control test. The reverse trend was detected for the endo-xylanase that show a greater effect on the wort viscosity. With regard to the starch degrading enzymes, β-amylases were comparable between durum and common samples and the α-amylase activities were on average higher in durum wheat malts.

The extract levels of the EBC congress worts produced with 100% durum wheat malts were comparable to the levels found using the common wheat malt, that show also higher viscosity and non-starch polysaccharides concentration.

Further studies are required for the optimization of the malting regime and the brewing process on pilot and industrial scale. It could be interesting to brew with 100% of durum wheat malt, using the wheat husks that during the harvest are left on the field by the thresher, as technical adjuvant for the mash filtration. The use of a brewing line with fine milling of the grist in combination with a membrane assisted thin-bed filter for the mash filtration is also a promising alternative.

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Table 1. Wheat quality traits

Variety	Moisture (% w/w)	GE (%)	TCW (g dm)	Proteins (% dm)	Starch (% dm)
Bidì	9.93±0.01^{e}	99.0±0.2^{ab}	49.3±0.44^{b}	8.86±0.07^{fh}	66.87±1.01^{a}
Capeiti	9.38±0.03^{f}	97.6±0.2^{cd}	36.5±0.06^{h}	9.66±0.24^{ef}	62.48±0.56^{bd}
Chiattulidda	10.46±0.03^{ab}	98.6±0.2^{b}	36.7±0.11^{h}	10.52±0.22^{cd}	66.25±1.56^{ab}
Farro Lungo	9.98±0.13^{de}	95.8±0.2^{e}	59.2±0.31^{a}	9.00±0.17^{fg}	65.32±1.00^{ab}
Francesa	9.02±0.07^{g}	99.2±0.2^{ab}	31.6±0.29^{i}	10.49±0.24^{ce}	60.75±1.33^{cd}
Gioia	10.51±0.23^{ab}	99.4±0.2^{a}	47.5±1.23^{c}	10.58±0.15^{c}	66.14±0.16^{ab}
Giustalisa	10.07±0.11^{ce}	98.8±0.2^{ab}	45.2±0.10^{d}	9.01±0.34^{fg}	63.21±0.99^{ad}
Inglesa	10.31±0.06^{ac}	99.2±0.2^{ab}	43.7±0.28^{e}	9.71±0.35^{df}	67.20±1.99^{a}
Martinella	10.02±0.03^{ce}	97.8±0.2^{c}	42.8±0.30^{e}	8.29±0.28^{gh}	67.08±2.17^{a}
Realforte	10.08±0.07^{ce}	98.6±0.2^{b}	41.2±0.03^{f}	10.09±0.21^{ce}	64.59±0.41^{ac}
Regina	10.26±0.09^{bd}	99.0±0.2^{ab}	41.4±0.15^{f}	11.80±0.15^{b}	63.91±0.76^{ac}
Russello	10.57±0.15^{a}	99.0±0.2^{ab}	46.9±0.29^{c}	11.77±0.02^{b}	63.89±1.57^{ac}
Trentino	10.31±0.05^{ac}	99.2±0.2^{ab}	41.1±0.36^{f}	9.17±0.01^{ef}	64.30±2.14^{ac}
Tripolino	9.79±0.01^{e}	97.6±0.2^{cd}	35.9±0.16^{h}	8.11±0.00^{h}	65.09±1.80^{ab}
Tumminia	10.25±0.04^{bd}	99.2±0.2^{ab}	31.6±0.04^{i}	12.63±0.66^{a}	59.74±1.25^{d}
Urria	9.97±0.02^{de}	97.0±0.2^{d}	40.4±0.46^{f}	9.79±0.25^{cf}	66.93±0.17^{a}
Control test.	10.31±0.18^{ac}	97.0±0.2^{d}	38.7±0.46^{g}	11.00±0.20^{bc}	63.31±1.06^{ad}

GE = germination energy; TCW = thousand corn weight; Values in the same columns followed by different letter are statistically different $p \leq 0.05$

Table 2. Wheat Malts Quality Traits

Variety	Moisture (% w/w)	TCW (g dm)	Proteins (% dm)	Soluble proteins (% dm)	Starch (% dm)	Color (EBC unit)
Bidì	4.1±0.30^{b}	47.93±1.05^{b}	8.51±0.07^{df}	3.12±0.23^{f}	63.54±1.07^{a}	3.0±0.3^{c}
Capeiti	3.3±0.01^{b}	33.18±0.42^{fg}	8.61±0.05^{df}	3.15±0.05^{f}	55.82±4.87^{cd}	3.5±0.0^{bc}
Chiattulidda	3.8±0.05^{b}	33.54±0.33^{f}	9.85±0.09^{bc}	3.50±0.19^{bf}	48.00±2.53^{ef}	3.3±0.3^{bc}
Farro Lungo	4.0±0.05^{b}	54.87±0.62^{a}	8.80±0.06^{de}	3.04±0.07^{f}	59.95±0.53^{ac}	3.3±0.3^{bc}
Francesa	3.4±0.01^{b}	29.30±0.13^{hi}	9.03±0.05^{d}	3.21±0.05^{ef}	48.69±2.14^{e}	4.0±0.0^{abc}
Gioia	5.3±1.00^{a}	42.04±0.21^{c}	8.73±0.33^{df}	3.82±0.21^{be}	60.65±3.06^{ac}	3.0±0.5^{c}
Giustalisa	3.7±0.01^{b}	41.77±0.04^{c}	8.24±0.05^{f}	3.24±0.05^{df}	59.85±0.90^{ac}	3.5±0.0^{bc}
Inglesa	3.4±0.01^{b}	42.12±0.14^{c}	8.69±0.05^{df}	3.28±0.05^{cf}	55.92±0.00^{cd}	3.5±0.3^{bc}
Martinella	4.0±0.30^{b}	41.61±1.04^{c}	8.18±0.11^{f}	3.61±0.14^{bf}	62.28±0.01^{ab}	4.3±0.5^{ab}
Realforte	3.9±0.01^{b}	38.60±0.16^{de}	8.45±0.05^{ef}	3.42±0.05^{bf}	45.41±0.48^{eg}	3.0±0.5^{c}
Regina	3.9±0.01^{b}	38.35±0.13^{de}	9.41±0.05^{cd}	3.34±0.05^{bf}	45.25±1.60^{eg}	3.0±0.5^{c}
Russello	4.1±0.30^{b}	43.10±1.67^{c}	10.40±0.43^{ab}	3.84±0.11^{bd}	42.13±0.23^{g}	3.8±0.3^{bc}
Trentino	3.7±0.05^{b}	38.19±0.98^{de}	8.44±0.16^{ef}	3.91±0.35^{b}	57.21±1.81^{bc}	3.3±0.3^{bc}
Tripolino	3.7±0.35^{b}	30.98±0.59^{gh}	7.02±0.05^{g}	3.62±0.31^{bf}	50.41±0.56^{de}	3.3±0.3^{bc}
Tumminia	3.8±0.01^{b}	28.09±0.76^{i}	10.91±0.35^{a}	3.88±0.03^{bc}	47.78±0.67^{ef}	3.5±0.3^{bc}
Urria	3.8±0.10^{b}	39.24±0.70^{d}	8.81±0.05^{de}	3.37±0.06^{bf}	42.61±0.02^{fg}	3.8±0.3^{bc}
Control test	3.7±0.01^{b}	36.41±0.99^{e}	10.32±0.34^{b}	4.87±0.54^{a}	57.00±1.81^{bc}	5.0±1.0^{a}

G.E. = germination energy; TCW = thousand kernel weight; Values in the same columns followed by different letter are statistically different $p \leq 0.05$

Table 3. Friability, PUG and WUG in different durum malts and control wheat malt

Variety	Friability (%)	PUG (%)	WUG (%)
Bidì	36.3±0.38^{h}	13.1±4.86^{cd}	3.0±2.32^{cd}
Capeiti	34.4±1.78^{hl}	16.7±1.84^{c}	2.3±0.07^{ce}
Chiattulidda	28.3±0.46^{o}	28.0±0.98^{ab}	8.2±0.19^{b}
Farro Lungo	32.2±1.80^{im}	27.5±1.10^{ab}	5.0±0.60^{c}
Francesa	42.3±1.92^{fg}	8.7±1.90^{de}	2.3±0.68^{ce}
Gioia	45.4±1.32^{ef}	1.3±0.70^{hl}	0.2±0.20^{de}
Giustalisa	40.3±1.66^{g}	7.2±0.18^{eg}	1.2±0.17^{de}
Inglesa	40.8±0.94^{g}	6.4±0.20^{eh}	0.8±0.13^{de}
Martinella	48.8±1.22^{de}	0.7±0.44^{il}	0.0±0.00^{e}
Realforte	40.2±1.49^{g}	2.1±0.32^{gl}	0.6±0.60^{de}
Regina	31.2±0.14^{lo}	5.5±0.32^{ei}	2.1±0.55^{de}
Russello	36.4±0.23^{h}	4.5±1.92^{el}	1.2±0.47^{de}
Trentino	50.3±1.30^{cd}	3.4±0.76^{fl}	0.6±0.44^{de}
Tripolino	53.9±0.36^{bc}	8.1±1.55^{df}	1.5±0.62^{de}
Tumminia	35.5±1.64^{hi}	30.0±2.80^{a}	13.0±2.58^{a}
Urria	29.2±0.19^{mo}	24.3±0.29^{b}	14.8±0.76^{a}
Control test	80.5±1.50^{a}	0.0±0.00^{l}	0.0±0.00^{e}

PUG partly unmodified grains; WUG = wholly unmodified grains; Values in the same columns followed by different letter are statistically different $p \leq 0.05$.

Table 4. β-glucans, arabinoxylans and arabinose to xylose ratio measured for wheat, wheat malts and wort

Landraces	Wheat			Malt			Wort		
	BG % dm	AX % dm	A/X	BG % dm	WEAX % dm	A/X	WBG mg/l	WAX mg/l	A/X
Bidì	0.19 ± 0.01^{g}	4.59 ± 0.31^{ab}	0.79 ± 0.02^{ab}	0.049 ± 0.01^{c}	0.49 ± 0.01^{f}	0.83 ± 0.00^{abc}	63.66 ± 4.58^{ac}	654.64 ± 41.87^{h}	0.53 ± 0.02^{gh}
Capeiti	0.20 ± 0.01^{f}	3.99 ± 0.35^{be}	0.71 ± 0.01^{c}	0.046 ± 0.01^{de}	0.68 ± 0.02^{bc}	0.73 ± 0.03^{def}	55.47 ± 0.57^{df}	1028.33 ± 10.80^{b}	0.53 ± 0.01^{gh}
Chiattulidda	0.22 ± 0.01^{c}	3.84 ± 0.48^{bf}	0.76 ± 0.04^{bc}	0.043 ± 0.01^{fg}	0.58 ± 0.01^{d}	0.74 ± 0.02^{de}	50.40 ± 1.73^{f}	804.60 ± 2.60^{de}	0.54 ± 0.01^{gh}
Farro Lungo	0.13 ± 0.01^{p}	3.88 ± 0.06^{bf}	0.86 ± 0.06^{a}	0.054 ± 0.01^{b}	0.61 ± 0.02^{cd}	0.77 ± 0.02^{d}	60.74 ± 3.79^{bd}	730.23 ± 31.85^{fg}	0.61 ± 0.01^{ab}
Francesa	0.23 ± 0.01^{b}	3.63 ± 0.20^{bf}	0.78 ± 0.01^{ac}	0.045 ± 0.01^{eg}	0.58 ± 0.01^{d}	0.74 ± 0.03^{d}	55.71 ± 1.88^{df}	717.79 ± 7.17^{fg}	0.62 ± 0.01^{ab}
Gioia	0.21 ± 0.01^{d}	2.90 ± 0.14^{f}	0.79 ± 0.01^{ab}	0.058 ± 0.01^{a}	0.53 ± 0.02^{ef}	0.79 ± 0.01^{bc}	66.27 ± 2.19^{ab}	735.82 ± 0.31^{fg}	0.61 ± 0.01^{ab}
Giustalisa	0.16 ± 0.01^{m}	4.22 ± 0.39^{be}	0.75 ± 0.01^{bc}	0.045 ± 0.01^{ef}	0.56 ± 0.02^{de}	0.77 ± 0.02^{cd}	54.93 ± 0.98^{df}	584.70 ± 0.84^{i}	0.58 ± 0.01^{cde}
Inglesa	0.21 ± 0.01^{e}	4.56 ± 0.10^{ac}	0.71 ± 0.02^{c}	0.045 ± 0.01^{ef}	0.70 ± 0.01^{b}	0.68 ± 0.00^{efg}	58.32 ± 4.03^{ce}	805.82 ± 5.98^{de}	0.52 ± 0.01^{h}
Martinella	0.16 ± 0.01^{mn}	3.50 ± 0.01^{cf}	0.75 ± 0.01^{bc}	0.045 ± 0.01^{ef}	0.63 ± 0.01^{cd}	0.83 ± 0.04^{ab}	57.57 ± 3.76^{ce}	760.51 ± 4.42^{ef}	0.54 ± 0.01^{fh}
Realforte	0.16 ± 0.01^{m}	4.34 ± 0.18^{bd}	0.81 ± 0.01^{ab}	0.043 ± 0.01^{g}	0.64 ± 0.02^{cd}	0.87 ± 0.00^{a}	57.86 ± 7.35^{ce}	851.23 ± 38.39^{cd}	0.58 ± 0.01^{cd}
Regina	0.18 ± 0.01^{i}	5.58 ± 0.42^{a}	0.77 ± 0.02^{bc}	0.049 ± 0.01^{c}	0.75 ± 0.01^{ab}	0.73 ± 0.00^{def}	56.25 ± 2.39^{df}	901.54 ± 15.35^{c}	0.57 ± 0.01^{df}
Russello	0.15 ± 0.01^{n}	4.32 ± 0.68^{bd}	0.82 ± 0.01^{ab}	0.048 ± 0.01^{c}	0.71 ± 0.01^{b}	0.75 ± 0.01^{d}	57.23 ± 2.05^{cf}	645.52 ± 35.50^{hi}	0.53 ± 0.01^{gh}
Trentino	0.23 ± 0.01^{b}	4.05 ± 0.50^{be}	0.78 ± 0.01^{abc}	0.045 ± 0.01^{ef}	0.77 ± 0.02^{a}	0.74 ± 0.03^{d}	54.72 ± 1.40^{df}	1017.77 ± 15.39^{b}	0.58 ± 0.01^{ce}
Tripolino	0.17 ± 0.01^{l}	3.14 ± 0.12^{ef}	0.76 ± 0.01^{bc}	0.048 ± 0.01^{c}	0.76 ± 0.01^{a}	0.74 ± 0.00^{d}	57.47 ± 1.64^{ce}	694.18 ± 5.03^{gh}	0.60 ± 0.01^{bc}
Tumminia	0.25 ± 0.01^{a}	3.44 ± 0.11^{df}	0.80 ± 0.01^{ab}	0.047 ± 0.01^{cd}	0.59 ± 0.03^{d}	0.76 ± 0.03^{d}	58.91 ± 1.74^{ce}	689.80 ± 2.50^{gh}	0.64 ± 0.01^{a}
Urria	0.19 ± 0.01^{h}	4.58 ± 0.27^{ac}	0.82 ± 0.03^{ab}	0.044 ± 0.01^{eg}	0.69 ± 0.01^{bc}	0.67 ± 0.01^{fg}	53.59 ± 1.99^{ef}	707.73 ± 13.61^{fh}	0.53 ± 0.01^{gh}
Control test	0.14 ± 0.01^{o}	3.90 ± 0.65^{bf}	0.62 ± 0.05^{d}	0.059 ± 0.01^{a}	0.79 ± 0.01^{a}	0.66 ± 0.02^{g}	70.15 ± 1.46^{a}	1140.46 ± 20.50^{a}	0.55 ± 0.02^{eg}

BG = β-glucans; AX = whole arabinoxylans; A/X = arabinose to xylose ratio; WEAX = water extractable arabinoxylans; WBG = wort β-glucans; WAX = wort arabinoxylans; Values in the same columns followed by different letter are statistically different $p \leq 0.05$

Table 5. Activity of the NSP and starch degrading enzymes detected in durum wheat malts

Variety	Endo-glucanases (U g^{-1} dm)	Endo-xylanase (U g^{-1} dm)	β-amylase (BU g^{-1} dm)	α-amylase (CU g^{-1} dm)
Bidì	1.63±0.03^{hi}	0.31±0.01^{d}	32.22±0.10^{e}	71.30±1.62^{hi}
Capeiti	3.05±0.09^{e}	0.38±0.02^{ac}	31.87±0.20^{e}	77.63±2.91^{eh}
Chiattulidda	2.03±0.20^{gh}	0.39±0.03^{a}	35.79±0.87^{d}	51.59±1.02^{l}
Farro Lungo	3.54±0.19^{d}	0.31±0.01^{de}	31.95±0.72^{e}	46.55±1.19^{l}
Francesa	1.43±0.12^{i}	0.25±0.01^{eg}	42.21±0.03^{a}	90.52±3.71^{c}
Gioia	3.20±0.14^{de}	0.30±0.01^{df}	35.24±0.09^{d}	76.04±0.68^{gh}
Giustalisa	1.97±0.18^{gh}	0.32±0.01^{d}	30.07±0.57^{f}	101.68±3.60^{b}
Inglesa	2.30±0.04^{fg}	0.22±0.01^{g}	32.88±0.28^{e}	71.95±1.59^{hi}
Martinella	2.19±0.01^{g}	0.32±0.03^{cd}	30.01±0.10^{f}	77.01±1.47^{fh}
Realforte	4.62±0.16^{c}	0.43±0.01^{a}	39.63±1.26^{b}	66.79±1.33^{i}
Regina	2.74±0.05^{ef}	0.39±0.01^{ab}	38.95±0.95^{bc}	108.68±0.80^{b}
Russello	2.82±0.09^{e}	0.24±0.01^{fg}	37.63±0.08^{cd}	84.61±0.10^{cf}
Trentino	4.51±0.17^{c}	0.23±0.03^{g}	27.92±0.76^{g}	87.31±4.25^{cd}
Tripolino	2.20±0.12^{g}	0.39±0.04^{a}	27.95±0.15^{g}	85.16±5.99^{ce}
Tumminia	5.40±0.20^{b}	0.33±0.03^{bd}	43.91±0.16^{a}	130.69±3.90^{a}
Urria	2.20±0.02^{g}	0.30±0.01^{df}	28.65±0.55^{fg}	81.08±1.25^{dg}
Control test	18.99±0.40^{a}	0.21±0.01^{g}	36.75±0.57^{d}	71.57±0.01^{hi}

BU = Betamyl Units; CU = Ceralpha Units; Values in the same columns followed by different letter are statistically different $p \leq 0.05$

Table 6. Standard analysis on congress wort

Variety	Extract (%)	Fermentability (%)	FAN (mg l^{-1})	pH	Viscosity (mPa.s)
Bidì	84.61±0.40^{ab}	75.60±1.14^{ab}	77.75±3.47^{f}	6.25±0.12^{ac}	1.67±0.01^{ef}
Capeiti	83.24±0.30^{ac}	75.08±0.55^{ab}	91.13±4.13^{d}	6.26±0.01^{ac}	1.56±0.01^{gh}
Chiattulidda	78.18±3.38^{d}	80.15±1.34^{ab}	81.77±2.60^{ef}	6.26±0.01^{ac}	1.67±0.01^{ef}
Farro Lungo	83.02±2.56^{ad}	72.94±7.01^{b}	77.68±4.57^{f}	6.28±0.02^{ab}	1.78±0.01^{c}
Francesa	83.04±0.51^{ad}	80.93±1.06^{a}	80.26±4.24^{ef}	6.21±0.01^{ac}	1.64±0.01^{f}
Gioia	84.75±0.96^{ab}	80.09±0.61^{ab}	100.96±5.04^{c}	6.23±0.02^{ac}	1.69±0.01^{ef}
Giustalisa	84.34±0.26^{ab}	80.53±0.80^{ab}	77.60±0.04^{f}	6.33±0.01^{a}	1.68±0.01^{ef}
Inglesa	82.61±2.90^{ad}	75.22±0.38^{ab}	102.72±0.29^{c}	6.16±0.01^{bc}	1.75±0.03^{cd}
Martinella	85.85±0.91^{a}	82.52±2.16^{a}	74.72±1.72^{f}	6.26±0.03^{ab}	1.73±0.01^{d}
Realforte	81.81±1.51^{ad}	77.91±2.62^{ab}	100.38±1.62^{c}	6.21±0.01^{ac}	1.68±0.01^{ef}
Regina	80.08±2.61^{bd}	79.71±0.44^{ab}	74.61±2.10^{f}	6.28±0.01^{ab}	1.71±0.03^{de}
Russello	82.32±0.37^{abcd}	75.30±3.83^{ab}	130.12±6.53^{a}	6.28±0.02^{ab}	1.84±0.01^{b}
Trentino	82.35±2.01^{ad}	79.27±0.78^{ab}	101.04±2.91^{c}	6.15±0.03^{bc}	1.79±0.01^{c}
Tripolino	84.85±0.37^{ab}	81.57±2.85^{a}	80.51±1.16^{ef}	6.15±0.03^{bc}	1.56±0.01^{gh}
Tumminia	81.82±0.49^{ad}	79.24±4.16^{ab}	87.46±0.31^{de}	6.13±0.01^{c}	1.53±0.01^{h}
Urria	79.12±4.29^{cd}	77.28±0.90^{ab}	80.40±1.39^{ef}	6.28±0.03^{ab}	1.59±0.03^{g}
Control test	82.97±1.18^{ad}	77.64±3.35^{ab}	116.69±5.39^{b}	5.97±0.14^{d}	1.92±0.02^{a}

FAN= free amino nitrogen;Values in the same columns followed by different letter are statistically different $p \leq 0.05$

Table 7. Pearson correlation coefficient obtained for the selected variables

	Proteins	Soluble protein	K. I.	Δ starch	Friability	WUG	Extract	Viscosity	β amylases	β-glucanase	Xylanase
Proteins	1										
Soluble protein	0.452	1									
K. I.	-0.442	0.592*	1								
Δ starch	0.256	-0.026	-0.203	1							
Friability	-0.042	0.781**	0.787**	-0.377	1						
WUG	0.325	-0.127	-0.390	0.467	-0.489*	1					
Extract	-0.485*	0.031	0.458	-0.734**	0.454	-0.649**	1				
Viscosity	0.270	0.483*	0.178	-0.167	0.481	-0.469	0.069	1			
β amylases	0.703**	0.169	-0.443	0.278	-0.085	0.040	-0.281	-0.030	1		
β-glucanase	0.436	0.828**	0.389	-0.176	0.782**	-0.133	0.004	0.527*	0.202	1	
Xylanase	-0.279	-0.408	-0.112	0.250	-0.427	0.134	-0.178	-0.602*	0.044	-0.350	1

*. The correlation is significant at level 0.05 (two-tailed).

**. The correlation is significant at level 0.01 (two-tailed).

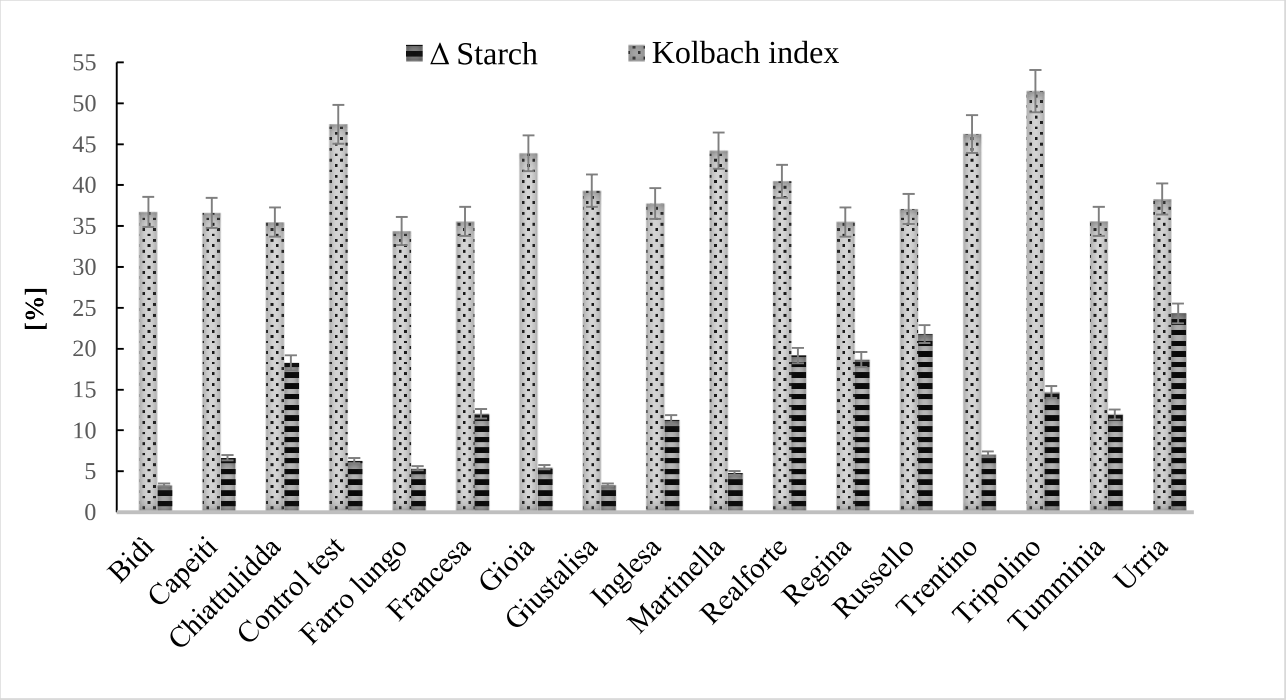

Figure 1. Trend for protein (Kolbach Index, %) and starch (Δ% starch) degradation.

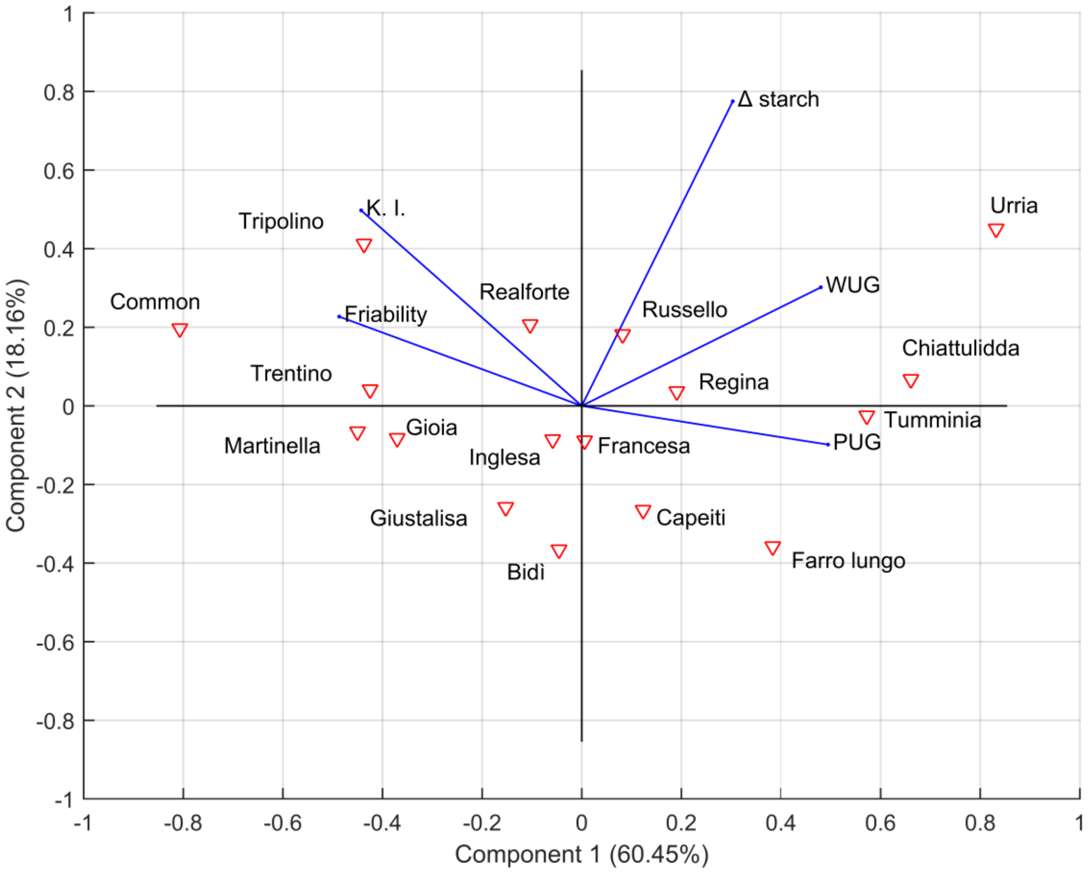

Figure 2. Genotype biplot for scores and loading of the PCA

Chapter 6

General conclusions

Conclusions

Currently, craft beers earn increasing favours among consumers of the countries with a strong tradition in beer, as well as in regions with no tradition in beer production and consumption.

This PhD dissertation explored different important aspects of the Italian craft beer sector, focusing on the Sicilian area, characterised by a relatively high number beer producers showing a strong dependence from the import of raw materials. In comparison to the national average production, the Sicilian companies show lower production volume that does not always ensure a reasonable margin of profitability, while showing attractive sales prices. The Sicilian craft beer sector consists of small enterprises with significant structural and productive differences and only a few companies were agricultural beer producers. Nevertheless, the sector shows a strong diversification of products. The use of local special ingredients is not so widespread among Sicilian brewers and occurs in a limited amount of total raw material required to beer production. In this regard, the spread of the Sicilian craft brewers would not seem to depend on geographical and local factors but probably was due to the positive global trend in craft beer consumption. The most of the Sicilian craft beers is produced brewing foreign raw materials, which have no local character. According to the recent regulatory updates, malt production and its processing into craft beer have enriched the range of products connected to agricultural and agri-food activities. The realisation of micro malthouses might further stimulate the growth of a local craft beer supply chain and help the development of the existent areas under cereal cultivation, such as the Sicilian hinterland. The results of the cost-benefit analysis have pointed out that size and typology of processing plants play a key role in the economic and financial feasibility of a malthouse. The potential feasibility for micro-malting systems, currently missing in Sicily and not widespread in Italy, may represent the link between farmers and brewers in the promotion of local products with unique characteristics and a strong connection with the production areas. In this regard, durum wheats (*Triticum turgidum*, subsp *durum* Desf.) are the main cereal crops of the Mediterranean area, and Sicily represents one of the major Italian producers. The suitability for malting was investigated for the first time on durum wheat, the results of the preliminary comparison between the durum wheat *Simeto* and the common wheat *Vivant* showed that genotype and different kilning-end temperature affect the malt quality attributes, mainly in term of extractable compounds and enzyme activities. For durum wheat malts, a 45 °C of final drying temperature positively affects Kolbach index, FAN, levels of enzyme activities and does not seem to influences the availability of non-starch polysaccharides in finished malts. Comparing *Simeto* and *Vivant* wheat malts dried at 70 °C, the common wheat had the strongest protein and starch degradation but showed the lowest enzyme levels. When the 40% of wheat malts was used in mashing, the level of extract, FAN and wort arabinoxylans increase. The wort produced using the durum and common wheat malts showed substantial differences in the availability of β-glucans and the wort viscosity. In our tests, the use in mashing of 40% of durum wheat malt results in low viscosity and reduced wort β-glucans concentration.

The EU agricultural policy, promoting the improvement of soil and the low inputs agronomic management, it was a driving force for the reintroduction of the old durum wheat landraces in marginal and rural areas enhancing biodiversity. The old durum wheat landraces are considered less suitable for bred and pasta making compared to new high yielding varieties. Considering the growing interest to investigate wheats with low protein and viscosity, characteristics suitable to malting and brewing, 16 old durum wheat landraces were studied.

The results showed that the durum wheats have optimal germination energy, showing on average lower protein, non-starch polysaccharides availability and comparable starch levels to the traditional malting wheat varieties. The malted durum wheats showed high variability in degradation intensity for protein, starch and in general for the overall endosperm modification with lower protein solubility and paler colour than the control test. The endo-glucanase levels were lower in durum wheat malts compared to the activities observed in our common wheat malt control test. The reverse trend was detected for the endo-xylanase that show a greater effect on the wort viscosity. With regard to the starch degrading enzymes, β-amylases were comparable between durum and common samples and the α-amylase activities were on average higher in durum wheat malts. The extract levels of the EBC congress worts produced with 100% durum wheat malts were comparable to the levels found using the common wheat malt that shows also higher viscosity and non-starch polysaccharides concentration. Further studies are required for the optimization of the malting regime and the brewing process on a pilot and industrial scale. It could be interesting to brew with 100% of durum wheat malt, using the wheat husks that during the harvest are left on the field by the thresher, as a technical adjuvant for the mash filtration. The use of a brewing line with fine milling of the grist in combination with a membrane assisted thin-bed filter for the mash filtration is also a promising alternative.

In conclusion, the results of this PhD thesis pointed out how it is possible to increase the product diversification through the valorisation of local raw materials. On this subject, a valuable tool, able to encourage the growth of a local chain for craft beers, could be represented by the 2014/2020 Rural Development Programme for Sicily. The identification of the most appropriate programme measures, supporting the local market segment of malting and brewing sector, should be combined with the improvement of the professional operators’ skills.

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