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Sourdough use in Bread Production: Review

***Ayed S. Amr** [*1] **and Ashraf M. Alkhamaiseh**[2]*

[1,2] Professor and graduate student respectively, Department of Nutrition and Food Technology, University of Jordan, Amman, Jordan11942.

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ABSTRACT

The nutritional, economic, and social value of bread as a staple food commodity leads to the interest in optimizing its production and extending its shelf life through the enhancement of its flavor, textural and nutritional properties and delaying staling and microbial spoilage. However, the freshness, flavor, and textural quality are still major concerns and areas of development for the bread-making industry. Sourdough technology as a tool for enhancing the quality of pan bread, as discussed and studied by many researchers worldwide from different viewpoints, was reviewed in this article. The increased interest in sourdough-produced bread is a result of consumers' demand for natural, flavor-intensive bread with good keeping qualities and shelf life to satisfy their quest for a more natural and healthier lifestyle. This review focuses mainly on describing the natural sourdough techniques developed by the conventional and modern approaches over the past decades in the production of healthier bread. The methods used in the production of sourdoughs as well as their effect on the quality of the various bread types are also reviewed.

Keywords: Sourdough, Sour bread, Dough ferment, Dough microflora, Bread quality, Natural yeast.

INTRODUCTION

Flat Arabic bread is a staple food for the Middle Eastern in general and Arab people in particular. According to the Department of Statistics in Jordan, the average annual per capita flatbread consumption of Jordanians is approximately119 kg (DOS, 2010). Flatbread, in addition to being a calorie carrier, plays a crucial role in a typical Arabic meal including sandwich preparation due to the property of pocket formation, wrapping, spooning of foods, plate lining, and others (Amr, 1988).

Traditionally, Arabic flatbread was produced for centuries at homes and small hearth bakeries with natural wheat flour microflora as a leavening agent which includes various types of bacteria and natural yeast. This mixed–culture leavening method resulted in doughs with various levels of acidity, hence the term sourdough, and consequently a bread with unique flavor due to its high

* Corresponding author.E-mail: ayedamr@ju.edu.jo

acid level and other components produced by the wild microbial cocktail. However, this practice gave way to the use of commercial pure yeast produced by specialized companies which resulted in the loss of the traditional nostalgic characteristic flavor of Arabic bread.

The aim of this work is to review the literature on the production of sourdough bread with different starter cultures including natural sourdough ferment and evaluate its effect on the sensory, rheological, and staling behavior of the resulting bread.

Methodology

Official scientific books and Internet browsing from different databases were used to recognize and to download review and research articles linked to the terms (natural sourdough usage in bread production, natural sourdough biotechnology, effect of sourdough on bread quality, sourdough preparation techniques, natural sourdough characteristics, sourdough bread aroma compounds and anti-staling effect of sourdough). The collection of the papers was done according to the nature of the sourdough used in the preparation of the bread since the current review is concentrating on naturally- prepared sourdough from wheat flour. Furthermore, the papers that were linked to the key terms “Flat Arabic Bread, Baladi Bread, and Kmaj Arabic Bread” were collected as a priority for this scientific review. Reference lists of identified studies were also searched to find additional articles and reviews. Any other topics related to sourdough of a western type of bread were also reviewed and taken into consideration for adopting the suitable techniques that can be applied in flat Arabic bread production.

Yeasted Bread Production Development

History: Bread has been known by man for more than 1500 BC by mural Egyptian paintings and the first formula may have consisted of wheat flour and water (with or without salt) without yeast or any other rising agents (Corsetti & Settanni, 2007). Raised doughs most likely were discovered by accident and introduced to the formula later in time after the advantages of yeasting were discovered (Gobbetti & Ganzle, 2013). This use of unfermented doughs is still practiced in the production of some bakery products like Matzo produced by the Jews on some religious occasions (Albala, 2013) and Shepherd's cake type of bread (Amr, 1988).

The earliest archaeological evidence of leavened bread was found during classic antiquity in the second millennium BCE in Egypt (Samuel, 1996) and probably in other cultures. The inclusion of yeast in the bread formula was found by man to impart good properties to the bread and became the common standard practice for the production of most bakery products worldwide (Carbonetto *et al*., 2018).

Fermented bread has been produced from self-rising doughs by spontaneous fermentation by natural yeast present if wheat or other types of flour are used in bread production (Samuel, 1996). Nowadays, in addition to yeast, bread is produced by a variety of means including mechanical development (Chin & Campbell, 2005) and chemical agents which perform the same functions that yeast does. Chemical leavening involves for example the use of ammonium bicarbonate which decomposes later and produces carbon dioxide, and this technique is limited to low-moisture baked products, such as cookies and crackers, wheat flour tortillas, and pancakes (Qarooni, 1996).

Bread Production with Wild Yeast: Ancient bread makers probably relied on spontaneous fermentation to leaven their doughs and may have developed sourdoughs at an early date by reserving a piece of fermented dough to inoculate the subsequent day’s batch (Kulp & Lorenz, 2003). Wild Saccharomyces yeasts have been cultivated by humans for thousands of years; winemaking dates back to at least 5000 BC, and desiccated brewer’s yeasts have been found in Egyptian beer residues and bread made about 1000 BC (Samuel, 1996). The use of wild yeast in bread production most likely was known in the same era of time. Modern *Saccharomyces cerevisiae* has evolved into a form different from that of its wild relatives and has become specialized in the rapid production of carbon dioxide and ethanol from sugars (Carbonetto *et al*., 2018).

As time went on, it is believed that the brewer's yeast was added to the dough to encourage the bread to rise more quickly. The utilization of beer yeast in bread making had been practiced by the Gallo-Roman bakers at the time of Julius Caesar but had been long since forgotten. It is thought that this ancient practice had been imported from the Middle East by the Phoenicians and transplanted to Marseille around 600 BC, but along with many other technological practices, this had disappeared following the fall of the Roman Empire (Kulp & Lorenz, 2003).

The Use of Yeast in Arabic Bread Production: The traditional way of Arabic bread production at home and bakery levels before the use of commercial yeast, involved the use of a piece of naturally fermented dough (called Khameerah) from the previous day as a starter. Most likely this Khameerah contained a myriad number of yeast species and bacteria along with the *Saccharomyces cerevisiae*, hence it is better described as ferment rather than yeast. The original mother dough is prepared from a lean formula consisting of local whole wheat flour, water, and salt and left to ferment for a few days. This is to be distinguished from the sponge used in the sponge and dough process whereby the sponge constitutes up to 30% of the batch (Amr, Personal Communication, 2021).

The use of wild microflora (yeast and bacteria) in this process gives doughs pronounced alcohol and acid smell as well as a sizable amount of air (CO_2) that causes the rising of the dough. The alcohol is evaporated by the heat of baking leaving the esters and other compounds which give the bread its characteristic flavor (Dong & Karboune, 2021). The so-produced bread is not standardized, and their flavors vary from household or bakery to another depending on the original ingredients and handling methods. Khameerah might be borrowed by neighbors or friends (Amr, Personal Communication, 2021). This reality dispels some belief by that Arabic bread is not fermented. The truth is that it undergoes fermentation but much shorter than the proofing stages followed in the production of the pan and another western type of bread, in addition, not enough time is given for the sheeted dough to rise before baking (Amr & Ajo, 2005).

Function of Yeast: Conditioning of dough by the gas produced by yeast and imparting desirable aroma and flavor to the baked goods are the primary functions of fermentation by bakers' yeast. Leavening is a complex process and therefore the rate of CO_2 production is determined by the activities of glycolytic enzymes of yeast while the retention of CO_2 produced by yeast is a function of wheat flour (Trivedi *et al*., 2008). The two physical processes that take place during dough fermentation are gas production by yeast and gas retention by the gluten network. During the fermentation process, yeast produces mainly carbon dioxide and ethanol, but the role of yeast goes much deeper than that of producing other secondary metabolites that may impact the final product quality. Yeast affects the volume, structure, flavor, color, and shelf life of each fermented product (Fleet, 2007). Due to the production of secondary metabolites through different metabolic pathways, yeast influences the flavor (by producing such compounds as esters, aldehydes, and ketones), color (by caramelization and Maillard reactions of sugars produced from carbohydrate hydrolysis by yeast enzymes), and improved shelf-life (acids and glycerol) of baked products. However, the foremost important characteristic, which is typically considered during strain selection, is the ability to ferment sugars anaerobically with adequate gas production (Reed & Nagodawithana, 1991).

Commercial Yeast Production: The production of baker's yeast exclusively for bread production dates from the latter part of the 19th century (Reed & Nagodawethana, 1991). It started with the production of distiller's yeast using grain mashes as a substrate for its propagation; however, this substrate was replaced later with sugar cane molasses in the United States and sugar beet molasses in Europe as cheaper raw material (Reed & Nagodawethana, 1991; Kulp & Lorenz, 2003; Trivedi *et al.*, 2008).

Bakers' yeast propagation is a highly aerobic process (Trivedi *et al*., 2008); however, the glucose breakdown proceeds in both anaerobic (Glycolysis) and aerobic (TCA cycle) conditions to pyruvate, so a continuous airflow is an important process required to alter the alcoholic fermentation process (Kulp & Lorenz, 2003). These reactions differ in energy yields as indicated by the following general equations:

1. Anaerobic fermentation (Glycolysis):

$$C_6H_{12}O_6 \longrightarrow 2CO_2 + 2C_2H_5OH + 2ATP$$

2. Aerobic fermentation (TCA Cycle):

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 38ATP$$

Production of baker's yeast starts by selecting suitable strains which are preserved as pure cultures, usually on agar slants in test tubes (Reed & Nagodawethana, 1991). They are frequently transferred by well-known pure culture methods and then propagated under strictly sterile conditions in a microbiological laboratory (Kulp & Lorenz, 2003). The production growth medium consists of a sterilized blend of clarified sugar cane or beet molasses, minerals (potassium, magnesium, sodium, sulfur, iron, copper, and zinc), vitamins (Vitamin B-complex), and minerals salts. During the major propagation steps, the nutrients are fed incrementally in synchrony with the growth of the yeast mass (Trivedi *et al.*, 2008). The feeding process and growth conditions are controlled by computer programs designed for specific yeast strains and yeast applications. The parameters which are controlled during fermentation include temperature, pH, aeration rate, the rate of feed of wort, nitrogen source, and phosphate source (Trivedi *et al.*, 2008). Strict sterility conditions are implemented to avoid cross-contamination during the production process, including equipment sterilization, use of air filters, and general plant maintenance (Kulp & Lorenz, 2003). Finally, a Special centrifugal separator is used to recover the fully fermented mashes chilled to (1–5ºC) and then kept in a refrigerated storage tank until further concentrated into filaments and dried with warm air in-tray, conveyor, rotary, vacuum, or fluid-bed driers (Trivedi *et al*., 2008) and the production process generally takes (5-7) weeks. The cream yeast may be processed into one of two general categories: compressed yeast, or active dry yeast. The compressed yeast is produced by dewatering the yeast cream with either rotary vacuum filters or filter presses with a final solids content of approximately 30% and this press or filter cake is packed and sold for commercial bakeries as a crumbly mass in bags or extruded in blocks that are wax wrapped and then it is cooled and shipped refrigerated (Reed & Nagodawethana, 1991).

Sourdoughs as rising agents in bread production.

Definition: Sourdough is a dough that tastes sour due to the high levels of acids produced intentionally or unintentionally by microorganisms or by the addition of acid. The bread produced from such dough is called sour bread (Gobbetti & Ganzle, 2013).

Natural Sourdoughs: The use of wild ferments with their varied microorganisms is expected to produce a number of desirable and undesirable products which include a number of organic acids, alcohols, esters, and other compounds (Yildiz *et al*., 2019). The situation is aggravated by the runaway uncontrolled fermentation which depends on the nature and concentration of the organisms in the ferment and the optimum fermentation time, temperature, and pH of the process. This resulted in non-uniform spontaneous carbon dioxide, acid, and alcohol production and the rising of the dough. These doughs were described as natural sourdoughs due to their sour smell and the bread produced therefrom is distinguished by its characteristic sensory and physical properties (Gobbetti & Ganzle, 2013).

Development of Sourdough: High acid dough (Sourdough) is likely to have originated in ancient Egypt around 1500 BC and was the first form of leavening available to bakers (Wood, 1996). It remained the usual form of leavening down into the European middle ages until it was replaced later by purpose-cultured yeast in the 19th century (Pollock & Cairns, 1991). Furthermore, it is still a daily practice in some countries of Africa and the Middle East (Gobbetti & Ganzle, 2013). Historically, the use of sourdough was necessary for rye bread production, because Baker's yeast (*Saccharomyces cerevisiae*) is not suitable as a leavening agent for rye bread for the prevention of ropeness (Chavan & Chavan, 2011). Sourdough has been used to produce the gluten-free millet bread known as "Karadish" (Amr, personal communication, 2021). Furthermore, the development of dried sourdoughs as convenient bakery ingredients, was initiated in the 1920s and 1930s and resulted finally in the early 1970s, in the development of naturally fermented organic dried sourdoughs, for use in a pan and other types of western bread (Brandt, 2007).

The Sour Fermentation Process: The sourdough leavening process usually occurs through three types of metabolic fermentation: alcoholic, lactic, and heterotactic fermentation. Naturally occurring yeasts are responsible for alcoholic fermentation that produces one mole of ethanol and one mole of carbon dioxide per mole of glucose. The various strains differ in fermentation characteristics due to differences in osmotic pressure sensitivity, acid and temperature tolerance, cell wall permeability, and sugar type fermentation ability (Kulp & Lorenz, 2003). In general, the microbial flora in the sourdough is different from that of the flour used as raw material (Gobbetti & Ganzle, 2013). Despite changes in raw materials or the bakery environment, sourdoughs are stable ecosystems due to specific metabolic adaptations or the production of antimicrobial compounds (De Vuyst & Vancanneyt, 2007). Based on that, the sourdough microflora is composed of stable associations of lactobacilli and yeasts, in particular, due to metabolic interactions and such microbial associations may endure for years, although the fermentation process runs under non-aseptic conditions. A reproducible and controlled composition and activity of the sourdough microflora is indispensable to achieve a constant quality of sourdough bread (De Vuyst & Neysens, 2005).

Sourdough Starter Culture Classification: Sourdough starter cultures are grouped based on two major criteria as follows.

Starter Culture Types Based on Technology of Their Production: On the basis of the technology applied in their production, sourdoughs have been grouped into four types (Siepmann *et al*., 2018) :

-Type I: sourdough is produced by using part of the previous fermentation (traditional sourdoughs). Usually, this is a natural mixture of wild yeast and bacteria.

-Type II is an industrial type of sourdough produced by using adapted yeast strains with lactic acid bacteria.

-Type III is often used by industrial bakeries, with constant quality and no end-product variations. Type III sourdough starters are referred to as inoculated (Type II) starters that are maintained according to traditional (Type I) methods.

The doughs of Types II and III require the addition of baker's yeast (*S. cerevisiae*) as a leavening agent, whereas Type I sourdoughs do not require this addition (Siepmann et al. 2018).

-Type IV is a mixture of types I and II produced at the laboratory scale.

Starter Culture Types Based on the Nature of the Fermentation:

Natural flora starter cultures produced under optimized conditions: This process involves propagation of the natural flora under optimized media and temperature conditions. These starters are produced by natural fermentation used as a processing step in bakeries where the starters are maintained and directly utilized in production. The natural starters can be refrigerated or frozen and shipped to other bakeries, and they have different descriptions usually referred to as mother sponge, however, in France, it is called, (levain), while in Germany called (Anstellgut) (Kulp & Lorenz, 2003). Basically, the environmental bacteria and yeasts colonize a flour-water mixture and ferment the digestible carbohydrates alongside other nutrients within the mixture. The microbial community is provisioned with resources through continuous refreshment with flour and water over 5–15 days which is also referred to as back slopping or propagation, during which part of the mixture is discarded (Gobbetti *et al*., 2016).

This type of starter is commonly referred to as Type I sourdough starters which are most commonly used in artisanal bakeries and usually kept at ambient temperature (20-30ºC) and can be refrigerated when not in use or at regular intervals. These starters usually begin with a near-neutral pH dough acidity level, which declines gradually due to the organic acids produced by lactic acid and acetic acid bacteria until full maturation. Mature Type I starters are highly acidic and usually, the number of bubbles, volume/height, smell, and flavor are the main parameters used to define a mature Type I sourdough starter (Gobbetti *et al*., 2016).

The traditional starter culture used for the production of Arabic bread and elaborated earlier belongs to this group. This type of starter culture used to be prepared at the home levels from whole wheat flour, milled in Buhr-like mills (Called Raha), and water to form a soft dough and then kept in a covered pot (usually clay pottery) with wet towels in worm place. Daily mixing with flour and water addition to refreshing the dough until sour smell and gas bubbles are obtained indicating that the "Khameereh" is ready to be used as a leavening agent for Arabic bread production, and this process lasts for up to 6 days (Amr, Personal Communication, 2021).

Synthetic Starter Cultures: These products, essentially flavor ingredients, are produced by compounding acids typically present in natural starters (Kulp & Lorenz, 2003). Commercially available sourdough starter cultures commonly consist of mixtures of different lactic acid bacteria groups to assure good acidification and aromatization in addition to the yeast (Chavan & Chavan, 2011). This type of starter is referred to as Type II starters which are usually fermented at higher temperatures for a quicker build of the desired bacterial organic acids and ultimately result in a lower pH system. It is easier to use at large scales of production because of its consistency, and they impart specific flavor profiles and can produce a different crumb texture or structure or loaf volume (De Vuyst, and Neysens, 2005). Specific bacteria are added to Type II starters to achieve unique (i.e., extra sour) organoleptic properties and enhanced shelf life, because ultimately the dough will be supplemented with bakers' yeast (or any other yeast which is acid-tolerant and an extreme CO_2 producer) to ensure a full, adequate rise (Ganzle & Zheng, 2019).

Mixed microbiologically - selected starter cultures: Generally, a mixture of selected lactobacilli grown on various bacteriological media then recovered, washed, and carefully dried to retain their activity (Kulp & Lorenz, 2003). This type of culture is called type III culture. It is normally used to inhibit ropiness by *Bacillus subtilis* bacteria which produces large quantities of Exopolysaccharides (Chavan & Chavan, 2011). Type III sourdough starters are dried versions of Type II that contain yeast and lactic acid bacteria strains resistant to drying and able to survive under these conditions (De Vuyst & Neysens, 2005). Therefore, Type III starters challenge the effects of ecological drift on the sourdough ecosystem by forcing competition between inoculated microorganisms and those naturally present in the local sourdough environment (Siepmann *et al*., 2018).

Microbial Composition of Sourdough:

Sourdough starter cultures and the resulting doughs contain several microorganisms including bacteria, yeasts, and even molds as contaminants in the natural cultures (De Vuyst *et al*., 2009). However, the important organisms are:

Bacterial Species

Sourdough bacteria cannot be seen as an independent group of bacteria existing only in sourdough. Rather, they can be described as a group of specially adapted varieties of lactic acid bacteria that are also common in other habitats (Kulp & Lorenz, 2003). The most relevant bacteria isolated from sourdough are shown in Table 1.

Table 1: Sourdough Most Common Lactic Acid Bacterial Species

Homofermentative LAB	Heterofermentative LAB
Lactobacillus casei**	*Lactobacillus brevis*
Lactobacillus delbrueckii	*Lactobacillus buchneri*
Lactobacillus farciminis	*Lactobacillus fermentum*
Lactobacillus plantarum**	
Pediococcus acidilactici	
Pediococcus pentosaceus	

***Adopted from (Kulp & Lorenz, 2003)**

**** Facultative heterofermentative according to Yildiz *et al*. (2019)**

With recent improvements in the biodiversity study of sourdough lactic acid bacteria, particularly sourdough ecosystems, several novel species have been isolated from traditional sourdough such as: *Lactobacillus (Lb.) mindensis, Lb. spicheri, Lb. rossiae, Lb. zymae, Lb. acidifarinae, Lb. hammesii, and Lb. nantensis*. The distribution of lactic acid bacteria species is highly variable from one sourdough ecosystem to another (De Vuyst et al., 2009). Less than 50 different species of Lactic acid bacteria, including *Lactococcus, Leuconostoc, Enterococcus, Pediococcus, Streptococcus, and Weissella*, have been isolated from sourdough with *Lactobacillus* strains are the most frequently observed, while *Leuconostoc* species, *and Enterococcus* species, were irregularly found in the sourdough ecosystem. However, among lactobacilli, the *Lactobacillus sanfranciscensis*, *Lactobacillus planatarum,* and *Lactobacillus brevis* were the most often isolated bacterial strains from the sourdough ecosystem (Hammes *et al*., 2005).

Yeast Species

The most common sourdough yeast species is *Saccharomyces cerevisiae*, but due to the lack of reliable yeast identification and classification systems, the figure of *S. cerevisiae* may be overestimated (Hammes *et al*., 2005). De Vuyst *et al*. (2002) investigated the microflora of a traditional wheat sourdough used for the production of San Francisco sour bread and they reported that the predominant yeast species was *Torulopsis holmii* which is a non-sporulating form of *Saccharomyces exiguus* that is responsible for the leavening action in the dough.

According to Yildiz *et al.* (2019), the most common dominant yeasts isolated from sourdoughs are: Saccharomyces cerevisiae, Saccharomyces exiguous, Saccharomyces dairensis, Saccharomyces ellipsoideus, Saccharomyces fructuum, and Saccharomyces inusitatus, Candida boidinii, Candida guilliermondii, Candida holmii, Candida stellate, Candida krusei, Candida tropicalis, Candida milleri, Hansenula anomala, Pichia saitoi, Hansenula subpelliculosa, Torulopsis holmii, Hansenula tropicalis, Pichia polymorpha.

Particularly, the yeasts associated with lactic acid bacteria in the sourdough ecosystem are *Saccharomyces* exiguous, Candida humilis (also called Candida milleri), and Candida krusei. In addition to that, there are other yeast species such as: Pichia anomala (also called Hansenula anomala), Saturnispora saitoi (also called Pichiasaitoi), Torulaspora delbrueckii, Debaryomyce shansenii, and Pichia membranifaciens also been reported (Hammes *et al.,* 2005).

Molds

A natural sourdough environment is not suitable for mold growth and the inhibitory effects are assumed to be the result of a combination of acids, low pH, and other antimicrobial substances present in the sourdough formed during the fermentation process. Acetic acid especially is shown to be very effective in mold and rope prevention, and the possible antimicrobial metabolites in sourdough might be bacteriocins or low molecular mass compounds with a wide spectrum of activity against gram-positive and gram-negative bacteria and fungi (Russo *et al*., 2017).

Sourdough Properties

Sourdough Stability

The stability of sourdough used for bread production is normally affected by several factors to be taken into consideration in order to keep the microorganisms active such as type of flour, fermentation conditions (pH, time, and temperature), and the microbial content, thus, problems of microbiota stability arise (De Vuyst & Vancanneyt, 2007).

In naturally fermented sourdoughs, the stability of the starter culture depends on the type of flour used and the fermentation conditions which cannot be controlled, however in synthetic sourdough production the problem of microbial stability in terms of species and strain composition should be carefully addressed to obtain stable microbiota during sourdough propagation and is essential to get standard and repeatable final products (Gobbetti & Ganzle, 2013).

Sourdough Storage

Storage of sourdough depends on several parameters which include: the pH value, the quantities of acetic and lactic acid, the quantity of ethanol, and the fermentable sugars present. The higher the pH, the more dissociated organic acids, which helps to preserve the sourdough's properties. Acetic acid is by far the most toxic since at pH 4.3 it's mainly in non-dissociated form whereas lactic acid is nearly non-dissociated (Debonne *et al*., 2020)

The liquid sourdough that is frequently used by bread manufacturers within the United States, is stored at (1–2°C), or at (4–5°C) which can be used to start a new fermentation without the refreshment step within 2–3 days maximum. One or two refreshments are needed in case of prolonged storage time for 10 days. Prolonged storage of the sourdough for a couple of months at (4–5°C) is possible when the ratio between water and flour is reduced (30% water: 70% flour). In this case, a firm sourdough is produced. Such a storage type necessarily requires sourdough reactivation (at least two refreshments) before use (Kulp & Lorenz, 2003). In general, as a consequence of the daily schedule in bread manufacturing, a portion of the sourdough is refreshed at least one time before its use. Refreshments are needed before reusing and in some cases, sourdough can be frozen and reused after refreshment (Gobbetti & Ganzle, 2013).

Sourdough vs. Sponge and Dough

Bread making, both at artisan and industrial levels, is traditionally a discontinuous process since the various stages of mixing, leavening, and baking are carried out on limited quantities of materials and in separated facilities. Discontinuous bread-making processes are performed using the straight-dough or the sponge-and-dough methods. Bread making with sourdough could be considered as a particular sponge-and-dough method (Gobbetti & Ganzle, 2013).

The traditional sponge-and-dough method is one of the most common bread production methods in many countries of the world including the USA and Canada (Cavanagh *et al*., 2010). It involves a two-stage process consisting of the preparation of a plastic sponge that is fermented with a certain amount of flour and when combined with the balance of flour, water, and other ingredients. On the other hand, the straight dough method is a single-stage process in which all ingredients are mixed simultaneously and fermented together. The Brew (liquid ferment) process is also the sponge and dough method whereby the plastic sponge is replaced with liquid ferment that can be transferred by pumping (Kulp & Lorenz, 2003).

Sourdough production, on the other hand, involves using special starter culture different from that used in the sponge and dough process. It is intended to produce acid in detectable quantities as compared to the ordinary *Saccharomyces cerevisiae* yeast used in the sponge and dough. In addition, the amount of the sponge used in the preparation of the dough is much higher than the ferment used in sourdough. Another difference is that while the sponge is taken from the previous dough mostly on the same day, the sourdough starter is usually taken from doughs prepared days before.

Modern Use of Sourdough in Bread Production

The increased interest in sourdoughs is a result of consumers' demand for bread without additives, flavor-intensive, and with good keeping qualities and shelf life. Moreover, the use of sourdough and the development of modern sourdough equipment and processes led to easier handling in the production of sourdoughs in artisanal and industrial bakeries (Kulp & Lorenz, 2003).

Methods of Bread Production Using Sourdough

Sourdough preparation can be affected through many different protocols. The main objective is to obtain a leavening agent that contains well-adapted resident microorganisms to produce sufficient CO_2 to leaven the dough, as well as organic acids and other metabolites to provide bread with good texture, sensory properties, and extended shelf life. Consequently, consecutive microbial re-inoculation often called ‘‘backslopping’’, of the microorganisms from a previous batch is used to maintain the microbial flora, which is adapted and selected to the process applied (Haggman & Salovaara, 2008).

The ratio between water and flour in the dough is indicated as dough yield (YD) and it deals with the dough consistency. Different flours have different capabilities to absorb water, and doughs of various consistencies are obtained having the same DY. Dough yield is calculated as follows (Decock & Cappelle, 2005):

DY = (flour weight + water weight) × 100/ flour weight.

To consider other ingredients in the formula, the expression is modified as follows:

DY = dough weight × 100/ flour weight.

Many different recipes and processes are used for sourdough preparation

worldwide; however, the most common commercial techniques for sourdough

preparation is the French, Polish and American systems that are described as

below:

The French System

Mother sponge preparation for obtaining the French "*pain au levain*" begins with quite firm wheat flour dough (dough yield (DY) of 150–152) with the addition of salt and flour. This dough undergoes a first fermentation step lasting 24 hours which allows early fermentation activity of flour resident natural yeast and lactic acid bacteria and results in a low carbon dioxide and organic acids release. The decrease of pH induces the activity of flour endogenous proteases which together with bacterial hydrolytic enzymes act on gluten and lead to a lower dough firmness (Calvel, 2001). The second step begins with the first refreshment of the dough by introducing oxygen and new fermentable carbohydrates into the mixture to stimulate microbial growth and activity and this is done by adding a quantity of flour and water to bring the dough yield to a value similar to the weight of the previously fermented dough. This dough represents the starting dough for the next refreshment. By applying such a procedure a sourdough with a steady fermentative and leavening capability is obtained (Gobbetti & Ganzle, 2013, Cauvain, 2003).

The refreshments are carried out at regular intervals of time (e.g. 7–8 hours), to maintain an equilibrium in the ratio between microbial communities. When the dough volume increases by three to fourfold with respect to the initial dough volume, new refreshment should be performed. The mother sponge dough (*levain chef*), which is obtained following the above procedure, represents the dough used to prepare the full sour needed to leaven the bread dough (Gobbetti & Ganzle, 2013).

The Polish System

Usually called the “Polish”, “Poolish” or “Viennese” methods were initially introduced in Poland and subsequently spread into Vienna at the beginning of the last century (Vogel *et al*., 1996). The “Poolish” premix is generally prepared by using 50–75% of the water required by the recipe, to which an equivalent amount of flour is added. This ratio gives a mass of low consistency that is left to ferment from 3 to 8 hours, according to the quantity of baker’s yeast added. This method gives sensory advantages and allows the formation of a delicate aroma, but the use of this method remained limited (Gobbetti & Ganzle, 2013).

Leavening with sourdough requires the use of a piece of dough from a previous batch (usually from 5-20% of the formula) which is fermented and stored under controlled conditions of temperature and humidity. Refreshing the mixture is important for dough development and maintains the microbial species of the sourdough (Gobbetti & Ganzle, 2013).

The American System

The American system relies on the mother sponge preparation on a mix of water and wheat or rye flours. The value of dough yield (DY) ranges from 225 (liquid dough with ratio water: flour of 1.25:1) to 250 (liquid dough with ratio water: flour of 1.5:1). These values of DY remain unaltered throughout the consecutive refreshments as well as the time and temperature of fermentation must be strictly controlled during each phase (Kulp & Lorenz, 2003). In the first step, the water/ flour mixture ferments at (32–35°C) for 24 hours in order to acidify the dough and at the end of this step, the first refreshment is obtained by adding flour and water to the previously fermented dough, without changing the value of DY. After 8 hours of fermentation at (32–35°C), the second refreshment is carried out and the dough ferments for another 16 hours. Refreshments are carried out every 8 to 16 hours between which the dough is allowed to ferment at (24–27°C). In order to calculate the amount of water and flour to be added at each refreshment stage a multiplicative factor of 4 is considered which means the weight of the fermented dough is multiplied by 4 every two refreshments which allows the ratio between the two ingredients to be maintained at a level of (1.25:1) (Gobbetti & Ganzle, 2013). By using this system, the value of DY remains constant until a sourdough with a pH value of (3.6–3.8) and TTA (total titratable acidity) of (16–20 ml NaOH/20g) of dough is obtained. The last fermentation of 8 hours at (24–27°C) is needed to give the sourdough the sensory and leavening aspects of the mother sponge. Generally, a sourdough with the above characteristics is obtained in approximately 5 to 7 days, after which it is maintained in an active state by storage at low temperature (e.g., 4°C) and subjected to refreshment at least once a day (Kulp & Lorenz, 2003).

Advantages of Using Sourdough in Bread Production

Sourdoughs play an important role in the preparation of bread e.g., improved dough machinability, nutritional properties through phytate hydrolysis, and other pan bread properties including loaf volume, crumb texture, and keeping properties (Hammes et al., 2005).

Sour Bread Flavor

The flavor is the most vital sensory attribute in terms of bread acceptability to consumers. The main stimuli that contribute to flavor perception during consumption are aroma, taste, texture, and mouthfeel (Taylor, 1996).

The aroma of wheat bread crumbs is specially formed from the fermentative activity of yeast and from the oxidation of flour lipids, while the aroma of bread crust is especially formed by Maillard reactions during baking (Purlis, 2010). Changes in the fermentation conditions, therefore, influence the aroma formation in the crumb. Sourdough fermentation has a well-established role in improving the flavor and structure of rye and wheat bread (Kulp & Lorenz, 2003).

The bread features a characteristic taste and smell, caused by the formation of volatile compounds that are mainly formed during baking, following the Maillard reaction between glucose and free amino acids, which are released during fermentation (Vogel *et al.*, 1996).

Microbial and enzymatic conversions of carbohydrates, proteins, peptides, and lipids in the dough result in the formation of alcohols, esters, and carbonyls creating flavor compounds relevant for the crumb odor. The crust odor is influenced by the thermal reactions during the process of baking. It is influenced by the fermenting microorganism, the fermentation temperature, and the type of flour (Hansen & Schieberle, 2005). Lactic acid bacteria can catalyze reactions such as deamidation, transamination, and decarboxylation, and their amino acid metabolism by-products also contribute to the flavor. The expression of the arginine deaminase pathway in *Lactobacillus sp*. promotes higher production of ornithine, and thus enhances the formation of 2-acetyl pyrroline that is responsible for the roasty note of wheat bread crumb produced by the sourdough method (Ganzle *et al*., 2007).

Sour Bread Shelf Life

The ability of sourdough to improve bread quality and increase its shelf-life has been described extensively by Arendt et al. (2007) and Dal Bello et al. (2007) who showed that the addition of sourdoughs helped increase the shelf-life of bread by inhibiting the growth of various microorganisms. The improvement of shelf life is attributed to the production of compounds like organic acids and dipeptides during the fermentation process (Ryan et al., 2009). Ryan et al. (2008) has also shown that sourdough can be used to significantly reduce the level of chemical additives in bread. It has been also reported to increase the folate content of both wheat and rye breads (Kariluoto *et al*., 2004). Katina et al. (2006) concluded that the anti-staling effect of combined use of bran sourdough and enzyme mixture was due to reduced starch retrogradation rate, slowed the increase in rigidity of polymer structure, and due to degradation of cell wall components leading to altered water distribution between starch–protein matrix.

Bread staling is an important issue for the bread industry as the shelf-life of wheat bread is markedly decreased by bread firming during storage (Katina *et al*., 2006). The application of lactic acid bacteria (LAB) in the form of sourdough has a positive effect on bread staling. One such effect is an improvement in loaf-specific volume, which is associated with the reduction in the rate of staling as measured by differential scanning calorimetry (Corsetti *et al.*, 2001). Antimicrobial benefits can also be obtained by the sourdough associated lactic acid bacteria, which can produce many antimicrobial substances, such as organic acids, CO_2, ethanol, hydrogen peroxide, diacetyl, fatty acids, phenylacetic acid, reuterin, and fungicins (Messens & De Vuyst, 2002). Sidhu *et al*.

(1997), measured the starch properties during staling of Arabic Bread (Khaboos) by using the differential scanning calorimetry (DSC) and the x-ray diffraction methods. They showed that the degree of crystallinity of white Khaboos increased with aging time while in brown Khaboos it reached a maximum after two days of storage. Furthermore, Sobhy *et al*, (2016), studied the effect of sourdough on shelf life and sensory characteristics of Egyptian type of Arabic bread (Baladi) and concluded that the fermentation of wheat flour dough by using sourdough containing 2% *S. cerevisiae* and 1, 2 or 3% of *L. plantarum* resulted in the formation of organic acids, that together with other compounds formed (bacteriocins) resulted in the antimicrobial effect on Baladi bread samples, as well as sourdough bread samples have scored higher sensory characteristics when compared to control. Moreover, Alian et al. (2018) revealed that sourdough Egyptian Baladi bread fermented with probiotic bacteria (free and encapsulated cells) have improved the organoleptic quality, color, production of organic acids (lactic and citric acids), CO_2, retarded staling and extended the shelf-life of the bread samples. On the other hand, sourdough lactic acid bacteria fermentation created an optimum pH for the activity of the endogenous enzymes (amylases and proteases) that improved the loaf volume; delayed starch retrogradation and bread firming, inhibited ropiness caused by spore-forming bacteria *Bacillus subtilis,* and enhanced the bread flavor (Corsetti *et al.,* 1998). Rope spoilage was also inhibited in wheat bread samples by adding 20-30g of sourdough per 100g of wheat dough containing *Lactobacillus plantarum* (Katina *et al*., 2002).

Nutritional Properties of Sour Bread

It is well known that certain strains of lactic acid bacteria have the capability to synthesize water-soluble vitamins such as those included in the B-group (folates B_9, riboflavin B_2, and vitamin B_{12}) (leBlanc *et al*., 2011). Recently, spontaneous roseoflavin-resistant derivatives of *L. plantarum* previously identified from natural sourdoughs were used during a standard bread-making and pasta making recipes, which resulted in a considerable increase of vitamin B_2 content (about a twofold and threefold increase in pasta and bread respectively), thus representing a convenient and efficient strategy for the production of vitamin B_2-enriched bread and pasta (Capozzi *et al.,* 2012).

The cereal grains, legumes, and oilseeds generally contain 1 to 4 percent by weight phytic acid which acts as the major storage form of phosphorous and strongly chelates divalent cations such as Ca, Fe, K, Mg, Mn, and Zn making them insoluble and thus unavailable for nutrition. Therefore, phytic acid is considered to be an anti-nutritional factor in humans and animals (Amr, 1986; Pandey *et al.,* 2001). Fermentation has been shown to enhance phytate hydrolysis by reducing about 60% of the phytic acid content of Arabic bread (Amr, 1986). Sourdough also favors mineral solubility in wheat bread as compared to traditional yeast fermentation. Here the polymers produced from *Lactobacilli* positively influence the properties of dough and bread including water absorption, dough rheology, and stability during frozen storage as well as loaf volume and staling properties of bread (Lopez *et al.,* 2000).

Tamani *et al*. (2013) reported an association between the increased Exo Polysaccharides (EPS) production during dough formation following the inoculation of ropy LAB starter cultures with increased bread volume and reduced staling over 5 days of storage. They suggested that the higher levels of EPS obtained with LAB have resulted in greater water retention, leading to the softer crumb structure of these bread, even though the Exo Polysaccharides (EPS) production did not correlate with the extension of shelf-life, thus their effect was more qualitative than quantitative. Recently, sourdough was found to be a helpful agent for regulating the digestibility of starch and, consequently, reducing the estimated glycemic index (eGI) in bread products. The eGI of sourdough bread was statistically lower than that of the control bread ($p < 0.05$). The greatest decreases in eGI were in the whole wheat sourdough bread samples obtained at 30 ◦C using the type-2 fermentation method (Demirkesen-Bicak *et al*., 2021).

Sensory Properties of Sour Bread

The main differences between ordinary bakers' yeast bread and sourdough fermented bread are physical and organoleptic. The physical characteristics include the higher crumb compactness and heavier crusts of sourdough bread, compared with those fermented by yeast, which exhibits high loaf volume and soft crumb with uniform crumb grain and a thin crust of pan bread (Decock & Cappelle, 2005. The organoleptic properties that are attractive to some markets are the acidic and intense flavor of sourdough fermented bakery products and the highly flavorful crust. The flavor of yeast-leavened bakery products is essentially neutral and mild, especially when they are fermented for a short time (Kulp & Lorenz, 2003).

Sourdough fermentation has proved useful in improving the texture and palatability of whole-grain and fiber-rich or gluten-free products and it may stabilize or increase the levels of bioactive compounds (Arendt *et al.*, 2007).

The degradation of protein during sourdough fermentation is one of the key features that influence the overall quality of sourdough bread. Proteolysis (breakdown of proteins into peptides) during sourdough bread fermentation is initiated by wheat or rye endogenous proteinases that are activated by the low pH. Further hydrolysis of peptides into amino acids is carried out by intracellular/extracellular peptidases of lactic acid bacteria. In addition, most sourdough lactic acid bacteria prefer peptides uptake rather than amino acids transport (Thiele *et al.*, 2004).

Extensive research studies worldwide have discussed and analyzed the sourdough nutritional, chemical, and biotechnological aspects of western types of bread, however, the literature on sourdough usage in Arabic bread processing is very limited and almost negligible(Catzeddu,2019; Sobhy *et al*.,2006).

Conclusions

Sourdough technology, although a traditional process when combined with modern manufacturing techniques, could improve nutritional value and yield healthier products for consumers. Sourdough helps to facilitate desirable texture and loaf volume to bread. Moreover, sourdough is useful for making bread products with an increased level of flavor compounds that ultimately increase customer satisfaction.

Sourdough technology can also be useful to reduce or eliminate the level of preservatives often used in baked products, as sourdough has shown antibacterial and anti-mold activity. Thus, sourdough could be a useful technique in extending the shelf life of Arabic flatbread using natural ingredients, improving the quality, and providing tastier and more convenient bread items to the Arabic cuisine.

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إنتاج الخبز بالعجينة الحامضية: مراجعة

عايد شاكر عمرو [1] وأشرف محمود الخمايسه[2]

[1,2]أستاذ وطالب دراسات عليا على التوالي/ قسم التغذية و التصنيع الغذائي/ الجامعة الأردنية/ عمان/ الأردن11942.

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ملخص

أدت أهمية الخبز الغذائية والاقتصادية والاجتماعية وكمادة غذائية أساسية، إلى الاهتمام بتحسين إنتاجه وإطالة مدة صلاحيته من خلال تعزيز خصائصه الحسية كالنكهة والقوام والقيمة التغذوية وتأخير التيبس والتلف الميكروبي. ومع ذلك، فلا يزال مستوى طزاجة ونكهة وقوام الخبز من أكثر مواضيع الاهتمام ومجالات التطوير في صناعته. في هذه المقالة، تمت مراجعة تقنية العجينة الحامضية كأداة لتحسين جودة خبز القوالب، كما نوقشت ودرست من قبل العديد من الباحثين في جميع انحاء العالم من وجهه نظر مختلفة. إن الاهتمام المتزايد بالخبز المنتج بالعجينة الحامضية هو نتيجة لازدياد طلب المستهلكين على خبز محضر من مكونات طبيعية يتمتع بنكهة قوية وخصائص حفظ جيدة لإرضاء سعيهم نحو نمط حياة طبيعي وصحي. تركز هذه المراجعة بشكل أساسي على وصف تقنيات العجين المخمر طبيعيا والتي تم تطويرها بالأساليب التقليدية والحديثة على مدى العقود الماضية في إنتاج خبز أفضل صحيا. كما تم فيها أيضا مراجعة طرق إنتاج الخبز بالعجينة الحامضية وتأثيرها على جودة أنواع الخبز المختلفة.

الكلمات الدالة: عجينة حامضية ، خبز حامضي، الخميرة الأم، نبيت العجين، جودة الخبز، خميرة طبيعية.