microbiologically by *Bacillus* species (Zak *et al.*, 1972; Jinap *et al.*, 1994). Therefore, the level of tetramethylpyrazine was proposed as an index of the degree of fermentation. Also the concentration ratio of primary and secondary methylbutanols in dry cocoa beans may be a useful indicator for controlling the fermentation process (Oberparleiter and Ziegleder, 1997b). 3-Methyl-1-butanol and 2-methyl-1-butanol arise from fermentative degradation of leucine and isoleucine within the seeds, while 3-methyl-2-butanol is formed biosynthetically in the fruit pulp and partly infiltrates the cocoa seeds during fermentation.

Special flavour-grade cocoas, mainly harvested in Venezuela, Trinidad and Ecuador (Arriba), reveal floral, tea-like and fruity aromas and contain significant concentrations (0.5–2.0 mg/kg) of linalool and further terpenoids (e.g. linalool oxides, ocimene and myrcene) which contribute to this pleasant note (Ziegleder, 1990; Pino and Roncal, 1992). Bulk cocoas from West Africa, Malaysia or Bahia carry a fairly strong inherent flavour and have comparably low levels of linalool. Therefore, the authors proposed the level of linalool or the concentration ratio of linalool and benzaldehyde as an indication of flavour-grade cocoas. As Schmarr and Engel (2012) reported, cocoa beans contain linalool primarily as (*S*)-enantiomer, with 0.2–0.8 mg/kg in basic-grade cocoas, 1.2–3.6 mg/kg in flavour-grade Arriba cocoas, but only 0.3–0.5 mg/kg in flavour-grade cocoas from Venezuela and Amazonia. Recently, linalool, ocimene and myrcene were found amongst the main fruit pulp volatiles in the defined flavour-grade cocoa genotypes (varieties) SCA6 and EET62, while they were low in the bulk cocoa CCN51 (Kadow *et al.*, 2013). The migration of these flavour components from the fruit pulp to the cotyledon tissue seems to take place already during fruit ripening and probably in the early stages of fermentation.

8.4 Roasting

8.4.1 The roasting process

The roasting of cocoa develops cocoa flavour, reduces moisture and acidity and releases the beans from the shell (see also Chapter 3). Cocoa is normally roasted at temperatures between 120 and 140 °C (248–284 °F) which is rather a low temperature in comparison to the roasting of nuts or coffee. Using modern equipment, cocoas can be roasted as whole beans (many different sizes), as nibs (broken beans) or as liquid cocoa mass, which is produced by a fine grinding of cocoa and liquefying within its own molten fat. Beans take about 30 min, nibs 12 min and liquor 2 min for roasting. Nib roasting has been associated with several advantages such as a more uniform distribution of heat, rapid evaporation of water and increase of output for the same amount of energy input (Jinap *et al.*, 1998). Special thin-film techniques were developed for the roasting of cocoa mass (Mohr, 1978; Schmidt, 1978; Rapp, 1981). The roasting of cocoa mass has the advantage of a better controlled and homogeneous roasting level,

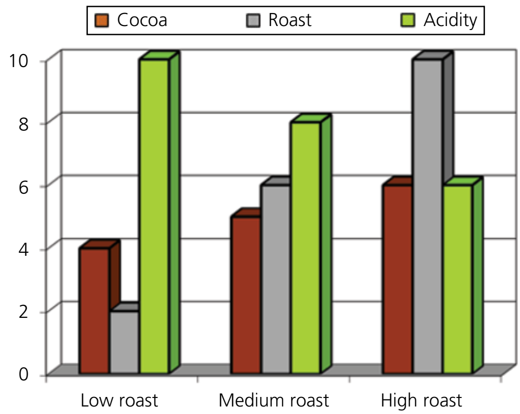

Figure 8.7 The effect of roasting conditions upon the taste of the final chocolate (Beckett and Lemmen, 2004). Partly reproduced from Beckett, S.T., *New Food*, **3**, 28–34, copyright 2006 with permission of Russell Publishing Ltd., Kent, UK.

of a shortened roasting time and of the partial removal of any excess acetic acid. While acetic acid was only slightly reduced (from 6 to 5 g/kg) in the industrial bean roasting (Jinap and Dimick, 1991), it was reduced from 6 to 3 g/kg during cocoa mass roasting (Nuyken-Hamelmann and Maier, 1987).

Prior to roasting, cocoa may taste astringent, bitter, sour, flat, musty or unclean. After roasting, cocoa possesses the typical intense aroma of cocoa and shows a reduced acidity. Roasting at temperatures higher than about 150 °C (300 °F), or for too long a roasting time, results in "over-roasted" cocoas, which have a significant bitter and burnt, coffee-like taste. Before roasting, pre-drying is necessary to reduce water content below 4%, and during roasting the moisture level decreases to about 2%. In industrial roasters, this pre-drying takes place as a separate processing stage. If roasted without pre-drying, cocoa would generate a cooked, flat aroma. As the formation of most flavour compounds is based on condensation or decomposition reactions, a surplus of moisture would hinder these reactions and furthermore evaporate volatile reaction products by steam distillation. For example, pyrazines may develop at low moisture levels only (Hartman *et al.*, 1984). The temperature/time to which the cotyledons are roasted has an effect on the flavour balance of the final chocolate. As the roasting is increased, not surprisingly, the degree of roast flavour increases, but other factors are also affected. As shown in Figure 8.7, the cocoa flavour intensity increases but the acidity decreases (Lemmen, 2004; Beckett, 2006). While specific cocoa volatiles, such as phenylic or furylic compounds, are already developed at low roasting temperatures, other volatiles, like pyrazines, need a higher roasting intensity.

8.4.2 Utilisation of flavour precursors

The flavour precursors interact in the roasting process to produce the desired cocoa flavour. Although the exact percentage of conversion depends upon the roasting parameters, there is a characteristic average for the utilisation of the precursors: