

1 Short Communication

2 Influence of the brewing temperature on the taste of 3 espresso

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10 **Abstract:** Very hot (> 65 °C) beverages such as espresso were evaluated by the International
11 Agency for Research on Cancer (IARC) as probably carcinogenic to humans. For this reason,
12 research into lowering beverage temperature without compromising its quality or taste is
13 important. For espresso, one obvious possibility consists in lowering the brewing temperature. In
14 two sensory trials using ISO 4120:2004 triangle test methodology, brewing temperatures of 80°C vs.
15 128°C and 80° vs. 93°C were compared. From the tested levels, espresso brewed at the lowest
16 temperature had the highest acceptance. However, most tasters were unable to distinguish
17 between 80°C and 93°C. The results of these pilot experiments proof the possibility to decrease the
18 health hazard of very hot beverages by lower brewing temperatures.

19 **Keywords:** coffee; espresso; hot beverages; temperature; esophageal cancer; sensory trial
20

21 1. Introduction

22 In 1991, coffee was first classified by the International Agency for Research on Cancer (IARC) as
23 "possibly carcinogenic for humans" (group 2B), as there had been a connection to increased risk of
24 bladder cancer [1]. This relationship could not be confirmed in later studies and coffee itself has been
25 reclassified into group 3 as "not classifiable" in 2016. In the earlier studies, the influence of tobacco
26 smoking had confounded the results of coffee consumption, because both behaviors often occur at
27 the same time [2]. The infusion of mate (*Ilex paraguariensis*) was evaluated as "probably carcinogenic"
28 (group 2A) in 1991 [3]. The significantly increased cancer risk may be based on the fact that mate is
29 typically drunk very hot. Epidemiological studies show that the esophageal cancer risk is increased
30 when mate is consumed very hot but not when cold [2,4]. Because of that, mate *per se* was included
31 during the 2016 re-evaluation in group 3 similar to coffee *per se*. Animal experiments suggest that a
32 carcinogenic effect occurs at a consumption temperature of 65 °C or higher, which was defined as
33 "very hot" [2,5]. Also considering epidemiological evidence (e.g. [6,7]), consumption of very hot
34 (>65°C) beverages independent of type were classified in 2016 as "probably carcinogenic to humans"
35 (group 2A) [2]. Several studies published subsequently to the IARC monograph further
36 strengthened the evidence between consumption of very hot beverages independent of type and
37 increased esophageal cancer risk [8,9].

38 In order to avoid the risk of injury in the pharynx due to an excessively high temperature, hot
39 beverages should not be consumed until they have cooled down [10]. In several studies, however, it
40 has been observed that hotter consumption temperatures are often preferred [11]. In a study from
41 southern Germany, the temperature at which coffee is perceived to be too hot was investigated. The
42 consumption temperature of coffee preferred by consumers is 63 °C. The average pain threshold is
43 67 °C [12]. However, coffee is typically brewed and served at temperatures higher than 65°C [10,13].

44 Espresso is a coffee beverage that is usually drunk immediately after brewing and without milk
45 addition that may lower its temperature [14]. For the extraction of espresso, the water temperature
46 (brewing temperature), has the most significant influence. If the brewing temperature is too high, a

47 higher amount of compounds will be extracted into the espresso and its taste will be strongly
48 influenced. Therefore, a maximum brewing temperature of 92°C was suggested. At higher brewing
49 temperatures, more bitter and more astringent substances are dissolved into the espresso and its
50 sensory quality is impaired [15]. However, field research detected that temperatures are often set at
51 much higher levels, probably because of unfounded fears about microbiological hazards [13,16,17].
52 Salamanca et al. confirmed that the bitterness and acidity of espresso is more pronounced at higher
53 brewing temperatures [18]. In a study by Andueza et al., the brewing temperature was also
54 described as the greatest influence on the quality of espresso [19].

55 With espresso, a lower consumption temperature can be achieved by lowering the brewing
56 temperature. This study will examine whether a lower brewing temperature of espresso has a
57 negative effect on its taste. Is it necessary to brew espresso very hot for an optimal aroma? Or can it
58 also be brewed at lower temperatures to achieve a pleasant espresso aroma? In order to find answers
59 to these questions, sensory trials are carried out to determine whether espresso brewed at 93 °C, for
60 example, differs in taste from espresso brewed at 80 °C.

61 2. Materials and Methods

62 The basic study design was investigating a perceptible sensory difference between samples of
63 two products using the forced-choice ISO 4120:2004 sensory analysis methodology "triangle test"
64 [20].

65 Individuals were given three espresso samples (2 temperature low/1 temperature high or 2
66 temperature high/1 temperature low in randomized fashion) and asked to make the following
67 decision: which of the three samples is different? They were additionally asked about the preference
68 regarding typicality of espresso taste of the deviating sample. The test material for sensory analysis
69 was espresso beans type Orphea (Maromas group, Tägerwilten, Switzerland). The espresso machine
70 was model ECM Synchronika (Espresso Coffee Machines Manufacture GmbH, Neckargemünd,
71 Germany).

72 In order to create the same conditions for each espresso extraction according to the Italian
73 Espresso National Institute [21], 7 ± 0.5 g freshly ground coffee powder is weighed directly into the
74 filter holder for each espresso. The coffee powder is distributed evenly in the filter carrier by
75 vibration. Then a tamper with a contact pressure of 25 kg is used to press the resulting coffee powder
76 cake. A fine balance placed under the espresso cup is used to ensure the correct quantity of espresso.
77 To start the process, the coffee machine's brewing lever is turned over. Meanwhile, the balance and
78 stopwatch are observed, and when an espresso quantity of 25 ± 2.5 g is reached, the brewing lever is
79 raised again to stop. If the espresso quantity is below or above the limit, or if the extraction time is
80 outside specification (25 ± 5 s), a new extraction attempt is started. Particular attention is paid to a
81 consistently uniform preparation method for the sensory trials.

82 Preliminary tests detected a clearly visible change in color due to the differences in brewing
83 temperature. With a brewing temperature of 80 °C, the espresso is very dark colored with foam on
84 the surface. Espresso at the maximum temperature of 128 °C is rather light brown in color and its
85 consistency as well as the appearance of the foam is also different. For this reason, precautions have
86 to be taken to ensure that during the tastings the test persons do not detect the deviating sample by
87 the existing color deviation. Therefore, a tasting chamber was set up, which prevents light from
88 entering. In addition, two lamps with color-adjustable LED light sources were used. Each color was
89 checked but only dark blue light, which shines directly into the cups, prevents optical differentiation
90 of the samples. Furthermore, white lids were placed on the espresso cups. The tasters were allowed
91 to only open the lid of one cup at a time, therefore making it impossible to visually compare the
92 samples even when moving them. Before each sample is tasted, the corresponding lid is removed
93 and then replaced.

94 To ensure that the two identical samples of each triplet actually have identical properties, an
95 espresso extraction with 25 ± 2.5 ml each is divided between two cups. The deviating sample is also
96 divided, the second sample is used for the next test. Since the coffee machine needs time to heat up
97 or cool down to the desired brewing temperature, it is essential to keep the espresso warm on

98 heating plates until it is tasted, ensuring that all three samples have the same temperature. The test
 99 can only be started once the three espresso samples have been equilibrated to the same consumption
 100 temperature of approximately 55 °C for a sensory test. 24 persons participated in two triangular
 101 tests. These included a total of 20 women and 4 men from different age groups. In the first triangle
 102 test, it was tested whether an espresso brewed at 80 °C differs from an espresso brewed at 128 °C. In
 103 the second test, the minimum brewing temperature of 80 °C is compared with the setting of 93 °C.

104 Power calculations were based on the ISO 4120:2004 [20] protocol and on Schlich [22]. ISO
 105 4120:2004 provides a baseline scenario in which testers are assumed to be able to discriminate with
 106 50% accuracy. To achieve statistical significance at a level of 0.05 for both α -risk (probability of
 107 concluding that a perceptible difference exists when one does not) and β -risk (probability of
 108 concluding that no perceptible difference exists when one does), at least 23 assessors are needed. For
 109 statistical analysis, the results of the espresso discrimination tests were applied to the significance
 110 tables of the ISO 4120:2004 based on Meilgaard et al. [23].

111 3. Results

112 Of a total of 24 test subjects, 10 individuals identified the deviating sample in both sensory tests.
 113 As shown in Table 1, 15 out of 24 people detected a difference between the espresso samples of the
 114 first triangular test (80°C vs. 128°C). A total of 13 people indicated that the sample brewed at 80 °C
 115 has the more typical espresso taste. In the second test, espresso was compared at a brewing
 116 temperature of 80 °C with a brewing temperature of 93 °C. Of the 24 test persons, 11 answered this
 117 test correctly (table 1).

118 **Table 1.** Results of ISO 4120:2004 sensory analysis using triangle testing for differentiation of
 119 espresso prepared using different brewing temperatures.

Brewing temperature	No. of assessors	No. of correct responses	Significance ¹	LCI/UCI ²
80°C vs. 128°C	24	15	yes ($\alpha = 0.01$)	0.19/0.68
80°C vs. 93°C	24	11	no ($\alpha = 0.20$)	-

120 ¹ According to ISO 4120:2004 [20]. For the non-significant trial, the minimum number of correct answers to
 121 conclude that a perceptible difference exists ($\alpha = 0.05$) would have been 13/24.

122 ² Lower and upper 95% confidence intervals (LCI/UCI) for triangle tests calculated according to ISO 4120:2004
 123 [20]. The limits can be interpreted as percentage of population that can perceive a difference between the
 124 samples [23].

125 4. Discussion

126 According to DIN EN ISO 4120, for a triangular test with a significance level of $\alpha = 0.05$ and
 127 with a number of test persons of $n = 24$, there is a minimum number of correct answers for
 128 determining a perceptible difference of 13 persons. It can therefore be concluded that there is a
 129 perceptible difference in Test 1 between the espresso sample brewed at 80 °C and the one brewed at
 130 128 °C on the basis of a triangular test.

131 For the second triangular test, however, since only 11 persons have correctly detected a
 132 difference in the triangular test, it is not statistically significant. Espresso brewed at 80 °C is not
 133 distinguished from espresso brewed at 93 °C by taste. During the sensory analysis carried out in this
 134 work, hotter brewed espresso was described as stronger, more bitter and more acidic, similar to the
 135 study of Salamanca et al. [18]. Our results are comparable to Andueza et al. [19], while different
 136 methodologies were used. In the case of Andueza et al. [19], the espresso samples were extracted at
 137 brewing temperatures of 88 °C, 92 °C, 96 °C and 98 °C. It was found that more solids were detectable
 138 in espresso as the temperature rises. The tasting panel found the espresso more bitter and astringent
 139 when it was brewed at 96 °C and 98 °C [19]. Also in the study of Chapko & Seo, a too hot coffee
 140 temperature was described as roasted and burnt [24]. The results of the previous studies correlate
 141 with the feedback of the tasting panels in the sensory analysis carried out here.

142 It is not recommended to extract espresso beyond a brewing temperature of 93 °C. For the
143 samples taken at the setting of the brewing temperature of 128 °C, there are only negative comments
144 on the sensory attributes. They are burnt, bitter, and strongly acidic. The theoretical background is
145 the higher the brewing temperature the more solids and less volatile substances can be dissolved in
146 the espresso, resulting in a negative taste. As a result, more bitter and more astringent flavorings are
147 dominant [15]. It is also interesting to note that the impression can be gained that espresso, which is
148 produced at 80°C was more preferred in the tastings carried out. It is therefore even advisable to
149 brew the espresso lower than the standard setting of around 90 °C. In this case, the risk of an
150 excessively high consumption temperature can be completely avoided. It is interesting that the
151 Italian Espresso National Institute suggests a temperature of $88 \pm 2^\circ\text{C}$ [21], which is a lower and
152 stricter setting than what Illy and Viani are suggesting ($90 \pm 5^\circ\text{C}$) [15]. However, in practice, at least
153 in many espresso bars in Germany, much higher settings appear to be in common use [13].

154 5. Conclusions

155 During the sensory examination it has been elucidated that espresso should not only be brewed
156 less hot for health reasons. The espresso samples that were brewed at lower temperatures are more
157 accepted by the tasting panel. At a brewing temperature of $>120^\circ\text{C}$, however, the espresso sample is
158 described as undrinkable. For this reason, the coffee machine manufacturers should introduce
159 adjustable brewing temperatures and suggest lower default settings in order to minimize the risk of
160 esophageal cancer and to improve sensory perception. The guideline of the Italian Espresso National
161 Institute, which allows brewing temperatures down to 86°C , but not over 90°C should be more
162 widely implemented [21].

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