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ORIGINAL PAPER

Effect of mango kernel flour addition on the phenolics profile, antioxidant activity and pasting properties of wheat flour

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Abstract Improving the antioxidant and pasting properties of wheat flour could help enhance its health benefits and industrial uses. Hence, this study evaluated the effect of mango kernel flour addition on the phenolics profile, antioxidant activity and pasting properties of wheat flour. Wheat flour (WF) was mixed with mango kernel flour (MKF) at the ratios of 100:0; 90:10; and 80:20, to obtain 100%WF, WF-10%MKF and WF-20%MKF blends, respectively. The flavonoids and phenolic acids profile; free radicals (2,2-diphenylpicrylhydrazyl [DPPH]* and 2,2′-azino-bis-3-ethylbenzthiazoline-6-sulphonic [ABTS]$^{*+}$) scavenging activities; amylose and amylopectin contents; and pasting properties of the 100%WF and the blends were determined. Flavonoids (rutin and quercetin) and phenolic acids (gallic, chlorogenic and caffeic acids) contents of the blends increased as the level of addition of MKF increased. The free radicals-scavenging activities of the blends also increased significantly ($P<0.05$) as the level of addition of MKF increased. The DPPH* SC_{50} reduced from 7.04 ± 0.86 mg/mL (100%WF) to 4.51 ± 0.64 mg/mL (WF-20%MKF); while the ABTS^{*+} scavenging activity increased from 22.13 ± 1.24 mg/mL (100%WF) to 33.76 ± 1.92 mg/mL (WF-20%MKF). The amylose contents of the blends decreased significantly ($P<0.05$), with a concomitant increase in their final and setback viscosities, as the level of addition of MKF increased. Hence, addition of MKF improved the antioxidant and pasting attributes of WF.

Keywords Wheat flour · Mango kernel flour · Polyphenolics · Antioxidant activity · Pasting properties

Introduction

Among the cereal grains, common wheat (*Triticum aestivum* L.) stands out as the most important edible cereal crop worldwide. It is largely cultivated, as it takes up to one-sixth of the total cultivated land mass globally [1]. Wheat is a key dietary staple food for humans, having high levels of carbohydrate and protein. It is used for the production of a variety of food products, such as cakes, bread and noodles, which are consumed frequently by many households in the world. Food products made from whole wheat flour contain high levels of antioxidants, mostly polyphenolics, which are prominent for their ability to protect humans against oxidative stress-related chronic diseases such as cardiovascular diseases [2, 3]. These antioxidants are deposited in the bran of the wheat which is usually removed when processing wheat flour [2], so as to obtain refined wheat flour with desirable technological qualities. This practice of removing the bran drastically reduces the antioxidant level of the flour. Consequently, total phenolic contents, total flavonoid contents and antioxidant activity are higher in the

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whole wheat flour than in refined flour [4]. Hence, the use of whole wheat rather than the refined flour has been suggested [5].

However, the presence of the bran and the germ interferes with the desired rheological properties in whole wheat flour, and this leads to food products, including bread, with inferior sensory qualities [6]. This is in contrast to processed wheat flour which has appealing rheological properties that improve the sensory qualities of the food products; thereby increasing consumers' acceptability of such products. Thus, processed wheat flour is usually the first choice for making flour-based food products in the food industries.

To compensate for the loss of antioxidants, synthetic antioxidants, including butylated hydroxytoluene, butylated hydroxyanisole and propyl gallate, are usually added to refined wheat flours; but these synthetic antioxidants have been suspected to be harmful to the health [7]. Against the potential harmful effects of synthetic antioxidants addition to the flour, blending wheat flour with other natural antioxidants-rich flours to form composite flour, could be a viable option for compensating for the losses. In addition to compensating for the loss of antioxidants, there is also the economic consideration for using composite flours, due to the high cost of wheat. Thus, in many developing countries, several research efforts have been initiated with the aim of promoting the use of composite flours, comprising wheat flour and the flours of locally grown crops such as cassava, for baking [8, 9]. However, the quality and consumers' acceptability of food products made from such composite flours depend on the flour properties and proportional composition of the composites [10]. Therefore, there is need to search for other locally grown crops with the potential to enhance the antioxidant and rheological properties of the wheat flour.

Mango (*Mangifera indica* L.), of the family Anacardiaceae, is an evergreen tropical plant with wide distribution. It is an economic crop that contributes about 50% of the tropical fruits produced globally [11], and ranks as the fifth most consumed fruit worldwide. The fruit is a rich source of vitamin A, vitamins B and C for human nutrition. Its mesocarp typically contains 84% moisture, 15% sugar, 0.5% protein and 0.5% fibers [12]. Flour of the seed kernels is composed of 72.73% carbohydrate, 13.68% fat, 4.59% protein, and 1.69% ash [13]. Usually, the seeds with the kernels are discarded as waste product after eating the juicy mesocarp. This practice, coupled with huge wastages arising from poor storage and processing techniques in developing countries, makes the mango fruit an unpleasant source of agricultural waste products during its season. However, in the South-eastern part of Nigeria, the kernels are used as thickener in traditional soups [14]. It has also been reported that the kernels are eaten by Indians during periods of food scarcity [12, 15]. In addition to its food uses, mango kernel also has important health value. Flour of the kernel has been reported to be rich in flavonoids (catechin, rutin, quercitrin, quercetin and kaempferol), and phenolic acids (gallic acid, caffeic, chlorogenic and ellagic acid) which have important health benefits [16]. Also, methanol extract of the flour was reported to inhibit some important enzymes (α-amylase, α-glucosidase and aldose reductase) implicated in type 2 diabetes and its complications such as retinopathy [16]. Recently, it was reported that mango kernel flour-supplemented diet exhibited anti-diabetic effect in streptozotocin-induced type 2 diabetes in rats [13].

In view of the medicinal and food applications of MKF, we hypothesize that it could be a low-cost source for improving the antioxidant and pasting properties of WF; thereby enhancing the health benefits and industrial applications of the WF. Hence, in this study, the effect of MKF addition (10% and 20%) on the phenolics profile, antioxidant activity and pasting properties of WF was evaluated.

Materials and methods

Samples collection

Wheat grains and ripe mango fruits samples were bought from a local market in Moniya, Ibadan, Oyo State, Nigeria. The samples were botanically identified at Botany Department, University of Ibadan, Nigeria; and were later sorted. The juicy mesocarp of the mango fruit was sliced off, and the kernels were removed from the endocarp manually. The fresh kernels were later chopped with kitchen knife. Subsequently, the samples were oven-dried to a constant weight at 40 °C for 72 h [17].

Preparation of wheat and mango kernel flours and their blends

The flours of the wheat grains and the mango kernel were prepared by grinding each sample into 0.5 mm particle size, using Marlex grinder. Wheat flour (WF) and mango kernel flour (MKF) were mixed in the ratios of 100:0; 90:10; and 80:20, to obtain the 100% WF, WF-10%MKF and WF-20%MKF, respectively, used for the experiments. The flours were packed in airtight containers and subsequently used for the study.

Preparation of flours extracts

Two gram of each flour sample was steeped in 20 mL of methanol overnight, and was filtered through Whatman

(No. 1) filter paper. The filtrate, subsequently referred to as extract, was used for the analyses.

Chemicals and reagents

All chemicals were of analytical grade. Acetonitrile, acetic acid, methanol, formic acid, gallic acid, chlorogenic acid and caffeic acid were purchased from Merck (Darmstadt, Germany). Rutin, quercetin, 2,2-DPPH and 2,2′-ABTS, Trolox and L-ascorbic acid (Vitamin C) were bought from Sigma Chemical Co. (St. Louis, MO, USA).

Quantification of flavonoids and phenolic acids using HPLC-DAD

Quantification of flavonoids and phenolic acids in the samples was carried out using HPLC-DAD comprising a Shimadzu Prominence Auto Sampler (SIL-20A) HPLC system (Shimadzu, Kyoto, Japan), equipped with Shimadzu LC-20AT reciprocating pumps connected to a DGU 20A5 degasser with a CBM 20 A integrator, SPD-M20A diode array detector and LC solution 1.22 SP1 software. Extracts of the 100%WF, 10%MKF-WF and 20%MKF-WF were injected into reversed phase Phenomenex C_{18} column (4.6 mm × 250 mm) packed with 5 µm diameter particles. The mobile phase contained solvent A [water: methanol: acetic acid (95:3:2, v/v/v)] and solvent B [acetonitrile: formic acid (98:2, v/v)], at a flow rate of 0.7 mL/min and injection volume 50 µL. Gradient program was initiated with 95% of solvent A and 5% of solvent B until 2 min, and changed to obtain 25, 40, 50, 70 and 80% B at 10, 20, 30, 50 and 70 min, respectively, as earlier described by Boligon et al. [18], with slight modifications. Extracts of samples and mobile phase were filtered through a membrane filter of 0.45 µm (Millipore), and then degassed by ultrasonic bath prior to use. The extracts were analyzed at a concentration of 20 mg/mL; the flow rate was 0.6 mL/min and the injection volume was 40 µL. Stock solutions of flavonoids and phenolic acids standards references were prepared in the HPLC mobile phase at a concentration range of 0.030–0.500 mg/mL. All chromatography operations were carried out at ambient temperature and in triplicate. Quantifications were carried out by integrating the peaks using the external standard method, at 254 nm (gallic acid); 327 nm (chlorogenic) and caffeic acids; and 366 nm (quercetin and rutin). The individual chromatography peaks were identified and their amounts were calculated by comparing their retention time with those of reference standards and by DAD spectra (200–600 nm). The calibration curves were as tabulated below:

Standard	Regression equation	r-value
Gallic	Y = 12367x + 1187.4	0.9997
Chlorogenic	Y = 13482x + 1132.5	0.9999
Caffeic acid	Y = 11659x + 1308.7	0.9996
Quercetin	Y = 12743x + 1309.8	0.9995
Rutin	Y = 13167x + 1250.9	0.9997

The limit of detection (LOD) and limit of quantification (LOQ) of the flavonoids and phenolic acids were calculated from the standard deviation of the responses and the slope using three independent analytical curves of each compound, as recently defined by Menezes et al. [19]. The LOD and LOQ were calculated as 3.3 and 10 σ/S, respectively; where σ is the standard deviation of the response and S is the slope of the calibration curve

Determination of DPPH* scavenging ability

The DPPH* scavenging ability of the extract was determined according to the method described by Cervato et al. [20]. Briefly, appropriate dilutions (2, 4, 6, 8 and 10 mg/mL) of the extracts totaling 1.0 mL were mixed with 3.0 mL of 60 µM DPPH*. The test reaction was allowed to proceed for 30 min in the dark, after which the absorbance was measured at 517 nm. A reference test (DPPH* solution without the extract), and a reference standard (DPPH* solution containing ascorbic acid) were included in the assay. The percentage DPPH* scavenging ability of the extract was calculated thus:

$$\%\text{ scavenging ability} = \left[\left(A517_{\underset{s}{\text{references}}} - A517_{\text{sample}}\right) \Big/ A517_{\text{reference}}\right] \times 100$$

where $A517_{reference}$ is the absorbance of the reference test; and $A517_{sample}$ is the absorbance of the test containing the extract.

Determination of ABTS*+ scavenging ability

The method described by Re et al. [21] was followed to determine the $ABTS^{*+}$ scavenging ability of the extracts. The $ABTS^{*+}$ was generated by mixing equal volume of 7 mM $ABTS^{*+}$ aqueous solution and 2.45 mM $K_2S_2O_8$, and incubating for 16 h at room temperature in the dark. This was followed by adjusting the absorbance of the reagent to 0.7 ± 0.02 with 95% ethanol at 734 nm. Subsequently, appropriate dilution of the extracts amounting to 0.2 mL was mixed with 2.0 mL of the $ABTS^{*+}$ solution. The test reaction was allowed to proceed in the dark for 15 min, after which the absorbance was measured at 734 nm. The

ABTS*+ scavenging ability of the extract was subsequently calculated from Trolox standard, and expressed as Trolox equivalent antioxidant capacity (TEAC).

Determination of amylose and amylopectin content

Amylose content of the samples was determined according to the method described by Juliano et al. [22]. A portion of 100 mg of each flour sample was mixed with 1 mL of 95% ethanol and 9.2 mL of 1 N NaOH; and the mixture was heated at 100 °C in a water bath for 10 min to gelatise the starch. After cooling to room temperature, 0.5 mL of diluted extract was mixed with 0.1 mL of 1 N acetic acid solution, 0.2 mL of iodine solution (0.2% I_2 in 2% KI) and 9.2 mL of distilled water. The test reaction was allowed to proceed for 20 min for color development. Subsequently, the absorbance was measured at 620 nm, and amylose content of sample was calculated using standard amylose.

Amylopectin content of the samples was calculated by difference using the formula previously reported by Juan et al. [23] as follows:

Amylopectin (%) = 100 − amylose (%).

Determination of pasting properties

Pasting properties of the flour samples were determined according to the method described by Deffenbaugh and Walker [24], using a Rapid Visco Analyzer (RVA) (model: RVA-4, Perten Scientific, Springfield, IL). The RVA was interfaced with a personal computer equipped with the Thermocline software supplied by the same manufacturer. A portion of 3 g of each sample was mixed with 25 mL of distilled water in a canister to form suspension, which was then covered with a paddle and loaded in the RVA. The paddle rotated at a speed of 920 rpm in the first 10 s to disperse the sample properly. The suspension was equilibrated at 50 °C for 1 min; heated to 95 °C at a rate of 6.0 °C/min; maintained at 95 °C for 5 min; cooled to 50 °C at rate of 6.0 °C/min, and finally held at 50 °C for 2 min. During these heating and cooling stages, a constant paddle rotating speed of 160 rpm was maintained, and each sample was measured in triplicate. The pasting profiles of the sample, including peak viscosity, trough, breakdown, final viscosity, set back, peak time, and pasting temperature, were read on the computer with the aid of the thermocline for windows software. The results were expressed in Rapid Visco Analyser units (RVU, 1 RVU ¼ 12 cP).

Statistical analysis

Results of replicate experiments, expressed as mean ± standard deviation (SD), were subjected to analysis of variance and least significant difference tests at 95% confidence level using SPSS statistical software package, version 17.

Results

The flavonoids and phenolic acids profiles of the 100%WF and the blends (WF-10%MKF and WF-20%MKF), as characterized using HPLC-DAD, revealed the presence of the gallic acid (retention time—t_R = 10.45 min; peak 1), chlorogenic acid (t_R = 20.11 min; peak 2), caffeic acid (t_R = 26.37; peak 3), rutin (t_R = 39.08 min; peak 4) and

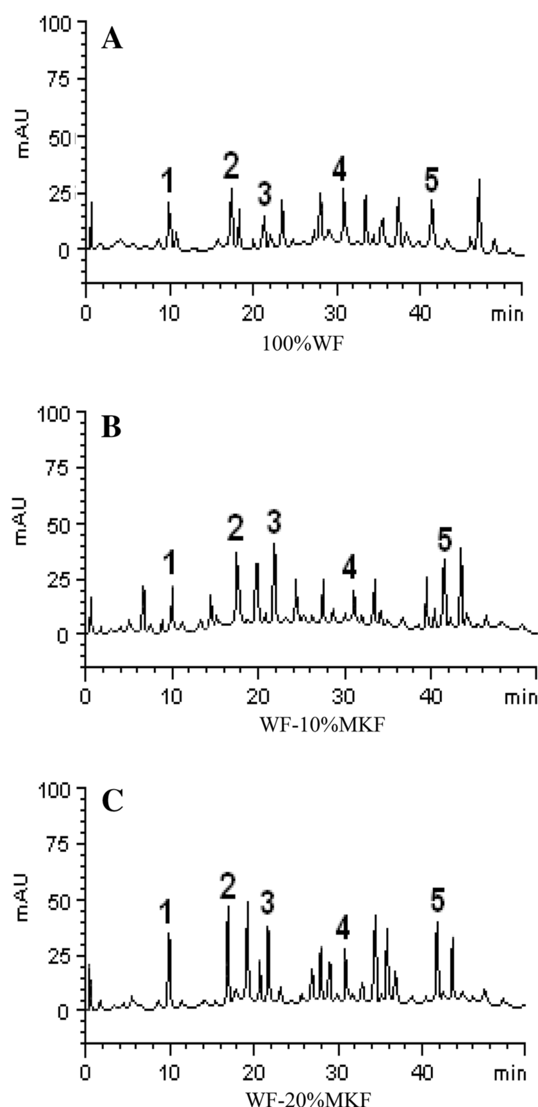

Fig. 1 Representative high performance liquid chromatography phenolics profile of 100%WF (**A**), WF-10%MKF (**B**) and WF-20%MKF (**C**) extracts. Gallic acid (peak 1), chlorogenic acid (peak 2), caffeic acid (peak 3), rutin (peak 4) and quercetin (peak 5)

quercetin ($t_R = 44.61$ min; peak 5) (Fig. 1a, c). The quantities of the various flavonoids and phenolic acids are presented in Table 1. The result shows that the addition of MKF led to a dose-dependent increase in the flavonoids and phenolic acids contents of the blends (WF-10%MKF and WF-20%MKF), relative to the 100%WF. The increase was significant ($P < 0.05$) for rutin, chlorogenic and caffeic acids at both levels of MKF addition (10% and 20%MKF); but only significant ($P < 0.05$) for quercetin and gallic acid at 20% level of the MKF addition. The result further shows that the flavonoids were in the order of quercetin > rutin in the 100%WF; whereas the phenolic acids were in the order of chlorogenic acid > gallic acid > caffeic acid. This order was however, not the same for the blends.

The free radicals-scavenging activity of extracts of the blends is presented in Table 2. The result shows that each extract scavenged DPPH* in a dose-dependent manner (Fig. 2). The DPPH* SC_{50} of the extracts significantly decreased ($P < 0.05$) from 7.04 ± 0.86 mg/mL in 100%WF to 6.09 ± 0.72 mg/mL and 4.51 ± 0.64 mg/mL in the WF-10%MKF and WF-20%MKF, respectively. This inverse trend indicates increasing order of free radicals-scavenging activity; with WF-20%MKF having the strongest DPPH*-scavenging activity, followed by WF-10%MKF and 100%WF. However, the DPPH* SC_{50} of ascorbic acid (0.01 mg/mL) was much lower than those of the blends,

Table 1 Flavonoids and phenolics acids composition of 100%WF, WF-10%MKF and WF-20%MKF extracts

Compounds	100%WF (mg/g)	WF-10%MKF (mg/g)	WF-20%MKF (mg/g)	LOD µg/mL	LOQ µg/mL
Rutin	0.51 ± 0.03^c	1.03 ± 0.04^b	1.45 ± 0.01^a	0.013	0.042
Quercetin	1.01 ± 0.01^b	1.11 ± 0.03^b	1.63 ± 0.04^a	0.029	0.095
Gallic acid	0.94 ± 0.01^b	0.96 ± 0.02^b	2.13 ± 0.4^a	0.017	0.056
Chlorogenic acid	1.28 ± 0.03^c	1.87 ± 0.02^b	3.09 ± 0.01^a	0.008	0.027
Caffeic acid	0.67 ± 0.01^c	1.95 ± 0.01^b	2.17 ± 0.01^a	0.024	0.079

LOD limit of detection; *LOQ* limit of quantification

Results are expressed as mean ± standard deviations (SD) of three determinations. Mean values followed by different superscript letters along the same row differ significantly at $p < 0.05$

Table 2 DPPH* SC_{50} and ABTS*+ scavenging ability of 100%WF, WF-10%MKF and WF-20%MKF extracts

Antioxidant activity	100%WF	WF-10%MKF	WF-20%MKF	Ascorbic acid
DPPH* SC_{50} (mg/mL)	7.04 ± 0.86^a	6.09 ± 0.72^b	4.51 ± 0.64^c	0.01 ± 0.00^d
ABTS*+ scavenging ability (µmol TEAC/g)	22.13 ± 1.24^c	26.48 ± 1.76^b	33.76 ± 1.92^a	NA

NA not applicable

Results are expressed as mean ± standard deviations (SD) of triplicate analysis. Mean values along the same row having different superscript letters differ significantly at $P < 0.05$

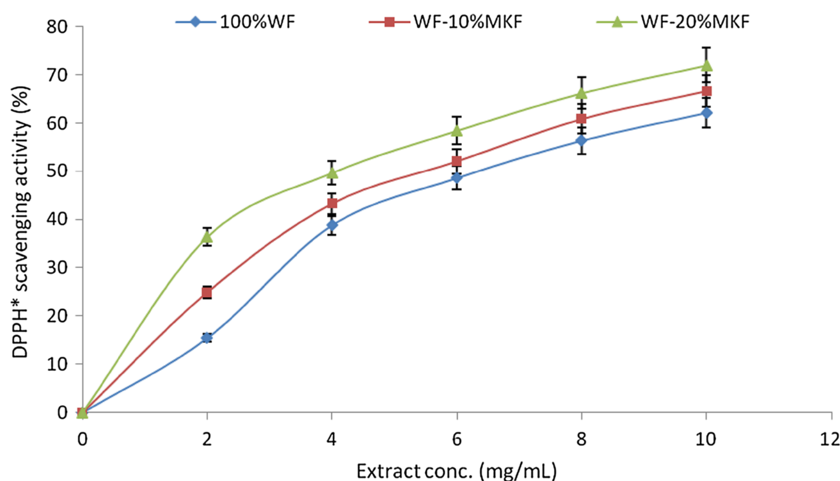

Fig. 2 DPPH % scavenging ability-extract concentration curves of 100%WF, WF-10%MKF and WF-20%MKF extracts

indicating that as a reference antioxidant, ascorbic acid has a stronger DPPH*-scavenging ability than the blends. Similarly, the ABTS^{*+} scavenging ability of the extracts increased significantly ($P < 0.05$) as the level of addition of the MKF increased. Hence, addition of MKF increased the free radicals-scavenging ability of the blends.

The amylose and amylopectin contents of the 100%WF and the blends are presented in Table 3. Amylose contents decreased significantly ($P < 0.05$) from 24.50 ± 0.83% in the 100%WF to 22.45 ± 0.78% and 20.11 ± 0.72% in WF-10%MKF and WF-20%MKF, respectively. This was accompanied with a significant increase ($P < 0.05$) in their amylopectin contents, from 75.50 ± 1.25% in the 100%WF to 77.55 ± 1.38% and 79.89 ± 1.96% in WF-10%MKF and WF-20%MKF, respectively.

Table 4 shows the pasting properties of the 100%WF and the blends. Relative to the 100%WF, the final and set back viscosities of the blends increased significantly ($P < 0.05$) as the level of addition of the MKF increased. Their peak time and pasting temperatures were comparable ($P > 0.05$); whereas their peak viscosities, trough and breakdown values were affected differently, as the level of addition of the MKF increased.

Discussion

In this study two flavonoids (rutin and quercetin) and three phenolic acids (gallic, chlorogenic and caffeic acids) were detected in the 100%WF and the blends. This is in agreement with a recent report by Sharma et al. [25], who also detected these five phenolic compounds, in addition to some other phenolic compounds in two different bread wheat varieties. However, in another previous study in which flavonoids and phenolic acids were quantified in some cereals including wheat, Kerienė et al. [26] detected rutin and some phenolic acids other than gallic, chlorogenic and caffeic acids; but did not detect quercetin in wheat samples. This variation may be due to differences in the genetic and environmental factors affecting the phytochemical constituents of the wheat samples [27], in relation to the regions where they were cultivated. The higher levels of rutin, quercetin, gallic acid, chlorogenic acid and caffeic acid quantified in the blends relative to the 100%WF, indicate that the addition of MKF improved the levels of these phenolic compounds in the blends. As stated earlier flavonoids, including rutin, quercetin, quercitrin, catechin and kaempferol; and phenolic acids, including gallic, chlorogenic, caffeic, and ellagic acid, have been reported to be abundant in mango kernel [16]. Thus, blending WF with MKF may help improve the health benefits associated with these two classes of polyphenols such as antioxidant, antidiabetic and antihypertensive activities [28, 29].

The abilities of extracts of the 100%WF and the blends to scavenge free radicals (DPPH* and ABTS^{*+}) indicate their antioxidant activities. The 100%WF scavenged both DPPH* and ABTS^{*+}. This is in conformity with the findings of other researchers, who also reported that wheat extract scavenged DPPH* and ABTS^{*+} [30, 31]. However, the SC_{50} (7.04 ± 0.86 mg/mL) of the 100%WF against DPPH* observed in this study is lower than the values reported by Heshe et al. (10.56 mg/mL) [32] and Fikreyesus (15.56 mg/mL) [33] for whole wheat flour extracts. A lower SC_{50} value indicates a stronger free radical-scavenging potential. Similarly, the ability of the 100%WF to scavenge ABTS^{*+} observed in this study (22.13 ± 1.24 μmol TEAC/g) is higher than the range (14.3–17.6 μmol of Trolox equivalents/g) reported by Moore et al. [30], for eight varieties of soft wheat. These variations in the free radicals-scavenging abilities observed for the 100%WF in this study and those reported by previous studies may also be explained by the differences in certain factors, including genetic, environmental, processing

Table 3 Amylose and amylopectin contents of 100%WF, WF-10%MKF and WF-20%MKF

Sample	% Amylose	% Amylopectin
100%WF	24.50 ± 0.23^a	75.50 ± 0.23^c
WF-10%MKF	22.45 ± 0.18^b	77.55 ± 0.18^b
WF-20%MKF	20.11 ± 0.06^c	79.89 ± 0.06^a

Results are expressed as mean ± standard deviations (SD) of triplicate determinations. Mean values along the same column having different superscript letters differ significantly at $P < 0.05$

Table 4 Pasting properties of 100%WF, WF-10%MKF and WF-20%MKF

Sample	Peak viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting temperature (°C)
100% WF	158.73 ± 0.03^b	61.64 ± 0.04^c	97.09 ± 0.01^a	153.18 ± 0.10^c	91.54 ± 0.06^c	5.45 ± 0.03^a	95.15 ± 0.07^a
WF- 10%MKF	155.85 ± 0.03^c	74.51 ± 0.01^b	81.34 ± 0.01^c	196.02 ± 0.03^b	121.51 ± 0.01^b	5.66 ± 0.01^a	94.81 ± 0.01^a
WF-20%MKF	165.84 ± 0.01^a	76.49 ± 0.01^a	89.35 ± 0.03^b	215.90 ± 0.03^a	139.41 ± 0.01^a	5.75 ± 0.03^a	94.87 ± 0.02^a

Results are expressed as mean ± standard deviations (SD) of triplicate determinations. Mean values along the same column having different superscript letters differ significantly at $P < 0.05$

conditions and method of extraction, which may all affect the antioxidant capacity of the wheat flour [27, 31].

Interestingly, the free radicals-scavenging effect of the blends increased as the level of addition of MKF increased, relative to the 100%WF. This improvement may be attributed to the increase in the levels of flavonoids and phenolic acids due to the addition of MKF. Other studies have demonstrated that extracts of plants foods and other plant products rich in flavonoids and phenolic acids possess strong free radicals-scavenging effects [34, 35]. Similarly, enhancement of the antioxidant activities of wheat flour through blending with other food crops has also been reported by previous studies [36]. Thus, blending WF with MKF may be beneficial in boosting its ability to prevent some diseases associated with oxidative stress [2, 3]. In addition to its antioxidant benefits to humans, addition of MKF to WF could also help protect the nutrients in the WF such as vitamins and unsaturated fatty acids that are prone to oxidative degradation [37].

The amylose and amylopectin contents of starchy grains, such as wheat, play important role in the functional attributes of the flours and the starches from such grains. The functional attributes, in turn, determine the food and industrial uses which the flours and starches from such grains are best suitable for. In this study, higher amylopectin contents were recorded in the 100%WF and the blends in relation to their amylose contents. This observation is in agreement with earlier reports that amylopectin is the major component of most plant starch [38, 39]. Furthermore, the amylose contents decreased with a concomitant increase in the amylopectin contents, as the level of addition of the MKF increased. Amylose content influences the retrogradation characteristics of starch, with high amylose starches increasing the retrogradation abilities resulting from the aggregation of amylose molecules which serve as nuclei during amylopectin retrogradation process [40]. On the other hand, low amylose content results in higher relative crystallinity of starch due to the reduced amorphous regions within the granule of the starch [41].

In addition to the important role that amylose and amylopectin contents play in determining the functional attributes of grain flours and starches, they are also important criteria for the glycaemic indices of the grains. Amylose is known to be slowly digested by the α-amylase present in the human duodenum due to its linear structural arrangement; unlike amylopectin that is digested very rapidly because of the multiple sites for enzymatic hydrolysis provided by its branched structure [42]. Moreover, the structural organization of amylose in the form of double helixes makes it possible for the inner part of the helix to accommodate the hydrophobic ends of polar lipids to form amylose–lipid complexes, thereby reducing the ability of amylase to access the sugar residues of the amylose [43]. This, therefore, suggests that addition of MKF could be a possible way of increasing the glycaemic index of WF-based meals, particularly for people with high energy demand, since its addition reduced the amylose content of the blends. This is supported by the reports of some previous studies that demonstrated that decrease in amylose level would increase the glycemic index of a food [44, 45].

Pasting properties describe the changes that take place in starch after gelatinization in excess water [46], usually after a definite heating and cooling cycle under shear forces. Pasting properties, and other rheological characteristics, impact the overall quality of food [46], and play a vital role in the commercial applications of starch, being it food or other industrial applications [47, 48]. To determine the pasting properties of the 100%WF and the blends, peak viscosity, trough, breakdown, final and set back viscosities, peak time and pasting temperature were measured (Table 4). The final and set back viscosities of the blends increased significantly ($P < 0.05$) as the level of addition of the MKF increased, relative to those of the 100%WF. The higher final viscosities exhibited by the blends suggest that they may be more suitable for making many food, textile and paper products that require starch with high viscosity [49], compared with the 100%WF. Final viscosity of a flour sample indicates its ability to form a gel after cooking and cooling. On the other hand, set back viscosity is an indication of the stability of the gel and its potential for retrogradation [50, 51]. Hence, the higher set back viscosities of the blends indicate a higher propensity of their starch molecules to disperse more readily in hot paste and to re-associate during cooling, relative to the 100%WF [52].

The breakdown values of the samples varied significantly, with 100%WF having the highest value, followed by WF-20%MKF and WF-10%MKF. This observation agrees with that of Julianti et al. [53], who recently reported higher breakdown viscosities in wheat flour, in comparison with composite flours. Breakdown indicates the ease of disintegrating swollen starch granules [54]. Similarly, the peak viscosities of the samples varied significantly, with WF-20%MKF having the highest peak viscosity, followed by 100%WF and WF-10%MKF. As reported by Ragaee and Abdel-Aal [55], the peak viscosity is related to the quality of end-product; it also indicates the viscous load a mixing cooker is likely to encounter.

The pasting temperature of the 100%WF and the blends were comparable ($P > 0.05$); suggesting that the 100%WF and the blends may have similar cooking time and paste stability [56]. Pasting temperature indicates the strength of associative forces within the starch granules [57], and its attainment is important for starch swelling, gelatinization and the subsequent formation of gel during processing [58]. An increase in pasting temperature has been reported to be related to higher amylose content [59]. Similarly, the paste

peak time of the 100%WF and the blends were comparable (P > 0.05). This is an indication that the rates of swelling and susceptibility to mechanical damage of their starch granules may be similar [60].

Conclusion

The addition of MKF to WF resulted in a dose-dependent increase in the flavonoids and phenolic acids contents, and free radicals-scavenging abilities of the WF-MKF blends. Amylose contents of the blends decreased as the level of addition of the MKF increased. The final and setback viscosities of the blends increased as the level of addition of the MKF increased. Hence, blending WF with MKF may be a low-cost approach to improve the antioxidant and pasting properties of WF. This may also enhance the health benefits, and food and industrial uses of WF.

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Compliance with ethical standards

Conflict of interest We declare that there is no conflict of interest regarding the execution and publication of this study.

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