Acta Poloniae Pharmaceutica – Drug Research, Vol. 72 No. 2 pp. 357–365, 2015 ISSN 0001-6837
Polish Pharmaceutical Society

EFFECT OF FORMULATION AND PROCESS VARIABLES ON THE RELEASE, MECHANICAL AND MUCOADHESIVE PROPERTIES OF IBUPROFEN TABLET FORMULATIONS

OLADAPO A. ADETUNJI, MICHAEL A. ODENIYI* and OLUDELE A. ITIOLA

Department of Pharmaceutics and Industrial Pharmacy, Faculty of Pharmacy, University of Ibadan, Ibadan, Nigeria

Abstract: A 2^4 full factorial analysis was used to study the individual and interactive effects of binder type, X_1; binder concentration, X_2; relative density, X_3 and tabletting technique, X_4, on disintegration time (DT), brittle fracture index (BFI), tensile strength (TS) and mucoadhesion time (MT) of ibuprofen tablets formulated by direct compression (DC) and wet granulation (WG), and containing *Entandophragma angolense* gum (ENTA) as binder, in comparison with hydroxypropylcellulose. The result of the FTIR and UV peaks suggests the absence of any interaction between ENTA and ibuprofen. Interactions between the polymers and ibuprofen were determined using FTIR and UV determinations. The ranking of the individual effects on DT and BFI was $X_2 > X_3 > X_1 > X_4$, on TS; $X_3 > X_2 > X_1 > X_4$ and on MT; $X_2 > X_1 > X_4 > X_3$. The effects of changing the binder from hydroxypropylcellulose to ENTA led to an increase in DT and decrease in TS, BFI and MT. Changing X_2 and X_3 to higher values increased the DT and TS. The interaction between X_1 and X_2 had the highest influence on BFI and MT, while interaction between "X_3 and X_4", and "X_2 and X_3" had the highest influence on DT and TS, respectively. Ibuprofen tablets prepared by wet granulation method and containing *Entandophragma angolense* gum showed lower capping/lamination tendencies and better mucoadhesive drug release profiles.

Keywords: *Entandophragma angolense* gum, mechanical/mucoadhesive properties, ibuprofen, factorial analysis

The search for competitive alternatives to the expensive excipients incorporated during the formulation development of new drug entities or modification of already existing ones has led to the investigation of naturally sourced substances as excipients in drug delivery systems because they are less expensive, biocompatible and biodegradable (1, 2). Thus, naturally available polymers are being exploited for use as pharmaceutical excipients (3–5).

Mucoadhesive drug delivery systems are designed to prolong drug retention, thus offering advantages over conventional dosages through reduced dosage regimen and improved patient compliance. Mucoadhesion can be defined as a state in which two components are held together for extended periods of time by the help of interfacial forces, of which one of the components is of biological origin (6). The use of naturally occurring polymers such as *Entandophragma angolense* gum (Family: Meliaceae) as excipients in mucoadhesive drug delivery systems necessitates the evaluation of the mechanical and mucoadhesive properties of such formulations. Mechanical properties of tablets can be evaluated using tensile strength and brittle fracture index as parameters (7, 8), while mucoadhesive properties can be assessed (*in vitro*) using mucoadhesion time (9, 10). Factorial experimental design allows evaluation of the statistical significance of the main effects and the interactions between such natural polymers and selected drug candidates (11, 12).

Entandophragma angolense gum (Family: Meliaceae) obtained as exudates from the incised trunks of the tree, has been used extensively in battery electrolytes and printing inks as thickeners (13). Dark colored *Entandophragma angolense* trees produce a reasonable quantity of gum while the light colored trees lack the gum (14). The gum obtained by bark-slashing is somewhat sticky, faintly scented, and has a bitter taste (13). Adetunji et al. (15) reported the use of *Entandophragma angolense* gum as a suspending agent in oral formulations containing sulfamethoxazole.

* Corresponding author: deleodeniyi@gmail.com; phone: +234-7088194371

In the present work, a 2^4 full factorial design has been used to study the individual and interaction effects of nature of binder (denoted by N), concentration of binder (denoted by C), relative density (denoted by D) and tableting technique (denoted by M) on the disintegration time, tensile strength, brittle fracture index and mucoadhesion time of the tablets.

Ibuprofen has been chosen for this study because of its poor compressibility and hence it requires a binder among other excipients to form tablets of satisfactory tensile strength.

MATERIALS AND METHODS

The materials used were: ibuprofen powder BP, (BDH Chemicals Ltd., Poole, U.K.), lactose BP, magnesium stearate BP, and hydroxypropylcellulose (HPC) (Aqualon, Hercules Incorporated, USA), all supplied by Bond Pharmaceuticals Ltd., Nigeria. *Entandophragma angolense* gum (family: Meliaceae) was obtained from the incised trunk of the tree available within the complex of the Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria.

Collection and purification of gum extract

The brown colored gum, collected as early morning exudates from previous incisions made on the trunk of *Entandophragma angolense* tree was weighed, allowed to dry and then thoroughly washed in chloroform/water (D/S) to remove associated earth particles. The precipitated gum was filtered, washed with diethyl ether and then dried in a hot air oven at a temperature of 40°C for 24 h. The dried gum was pulverized and passed through a number 60 mesh sieve (250 µm) (10, 16). The percentage weight of the purified and dried gum obtained from the exudates was then calculated. The dried gum (0.005 g) was dissolved in water, mounted on the microscope and observed for the presence of any foreign organic matter to determine the level of gum purity (17).

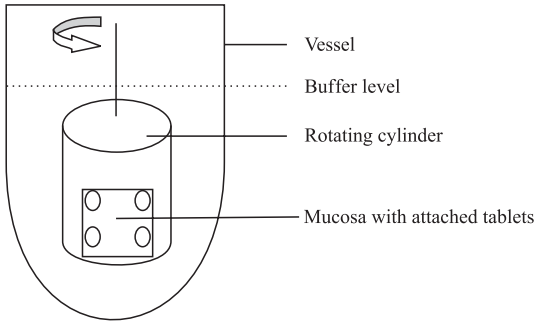

Figure 1. Rotating cylinder apparatus for mucoadhesion studies

Fourier Transform Infrared (FTIR) analysis

Spectra were obtained for the *Entandophragma angolense* gum, gelatin or HPC and ibuprofen using a Nicolet Magna-IR, 560 spectrometer.

A quantity (5 mg) of each of the completely dried powdered samples was weighed and then dispersed in 200 mg potassium bromide (pellet procedure). Signal averages were obtained at a resolution of 4 cm^{-1}.

UV analysis

Various mixtures of *Entandophragma angolense* gum or hydroxypropylcellulose and or ibuprofen were scanned in the wavelength range 190-300 nm. The maxima at 265 nm and 221 nm were monitored for wavelength shifts on a model DU-7400 spectrophotometer (Beckman, Fullerton, CA).

Preparation of granules

Batches (250 g) of a basic formulation comprising of ibuprofen, lactose, and *Entandophragma angolense* gum (or hydroxypropylcellulose), at a ratio of 6 : 3 : 1, respectively, were dry mixed for 5 min in a planetary mixer (Model A120, Hobart Manufacturing Co., U.K.) and moistened with appropriate amount of paste of the binding agent *Entandophragma angolense* gum (or hydroxypropylcellulose) to produce samples containing different concentrations of the binder.

Massing was continued for about 5 min and the wet masses were granulated by passing them manually through a no. 12 mesh sieve (1,400 µm). The granules were dried in hot air oven for 16 h at 60°C. The dried granules were then re-sieved through a number 16 mesh sieve (1,000 µm), before they were stored in air-tight containers.

Preparation of tablets

Wet granulation

Granule size fractions (500–1,000 µm) were used to prepare the tablets (400 ± 5 mg) using a Carver hydraulic hand press (model C, Carver Inc, Menomonee Falls, Wisconsin, USA), equipped with a 10.5 mm flat faced punch and die set lubricated with a 1% dispersion of magnesium stearate in acetone prior to compression.

Different compression pressures were employed to obtain different relative densities, ρ_r,

Table 1. Formulae for compressed tablets.

Formulations (% w/w)	A	B	C	D	E
Ibuprofen	5	5	5	5	5
Polymer (*Entandophragma angole*nse or hydroxypropylcellulose)	-	2.5	5.0	7.5	10.0
Talc	2	2	2	2	2
Spray dried lactose	93	90.5	88	85.5	83

for the tablets. The tablets were stored over silica gel for 24 h to allow for elastic recovery and hardening prior to measuring their weights and dimensions. The packing fractions (relative densities), ρ_r, of the tablets were calculated using the equation:

$$\rho_r = W / V\rho_s \quad (1)$$

where V = volume of tablets, W = weights of tablets, ρ_s = particle density of formulation.

Direct compression

The formulae for the compressed tablets are given in Table 1, and were prepared initially by premixing the *Entandophragma angolense* (or hydroxypropylcellulose) and ibuprofen for 15 min. Subsequently, lactose and talc were incorporated and the resulting composition was mixed for further 15 min. Compression was carried out at predetermined loads using a Carver hydraulic hand press, equipped with a 10.5 mm flat faced punch and die set lubricated with a 1% dispersion of magnesium stearate in acetone prior to compression.

Crushing strength and friability tests

Ten tablets from each formulation were tested for diametrical crushing test using the Erweka TBH 28 hardness tester (Apparatebau GmbH, Germany). Measurements were made in quadruplicate and the crushing strength results were accepted only if the samples split clearly into two halves. Tablet friability was determined using the Veego tablets friability apparatus (Veego Scientific Devices, Mumbai, India).

Determination of tensile strength and brittle fracture index

The tensile strength of the normal tablets (T) and apparent tensile strength of those containing a hole (T_o) were determined at room temperature by diametral compression (Erweka TBH 28 hardness tester). Measurements were made in triplicate on individual tablets and the results accepted only if the samples split clearly into two halves. Tensile strength (MNm^{-2}) calculated from equation 2 (18):

$$T \text{ (or } T_o) = 2F/\pi dt \quad (2)$$

where F is the load (MN) needed to cause fracture, d is the tablet diameter (m), and t is the tablet thickness (m).

The brittle fracture index (BFI) of the tablets was calculated from T and T_o by equation 3:

$$BFI = 0.5\,[(T / T_o)] - 1 \quad (3)$$

where T and To are as defined above (5, 18).

Disintegration test

Tablet disintegration time was determined in distilled water, at 37 ± 0.5°C with the Apex disintegration testing apparatus (Apex Construction Ltd.; Northfleet, Gravesend, Dartford, Kent, UK). Determinations were made in triplicate.

Mucoadhesion studies

Mucoadhesion studies were carried out to determine the time of detachment (mucoadhesive strength) of ibuprofen tablets attached to freshly excised intestinal mucosa of pig.

The rotating cylinder method, which is a slightly modified dissolution apparatus described in the United States Pharmacopoeia (USP) was used (Fig. 1). An intestinal segment of the mucosa was fixed on a stainless steel cylinder with the basolateral side facing the cylinder. The tablets were pressed on the apical side and the cylinder was transferred into a medium containing 500 mL of phosphate buffer, pH 7.4. The rotation speed was set to 60 rpm. The time taken for the tablets to detach from the mucosa was observed for tablets prepared by both wet granulation and direct compression techniques.

Factorial experimental design

To study the effects of nature of binder (denoted by N), concentration of binder (denoted by C) and relative density (denoted by D) and tableting technique (denoted by M) on the disintegration time, tensile strength, brittle fracture index and mucoadhesion time of the tablets, the experiments were performed based on the statistical modulation proposed by Woolfall (11). The basis of the experiment was to utilize a two-level factor using the four variables,

that is 2^4, and maintain a factorial structure. The levels are "high" level (denoted by the subscript H) and "low" level (denoted by the subscript L)

Using the above nomenclature, the expected combinations are represented by the following:

$N_H C_H D_H M_H$, $N_H C_L D_L M_L$, $N_H C_H D_L M_L$, $N_H C_H D_H M_L$
$N_H C_L D_H M_L$, $N_H C_L D_L M_H$, $N_L C_H D_H M_H$, $N_L C_L D_H M_H$
$N_L C_L D_L M_H$, $N_L C_L D_L M_L$, $N_L C_H D_L M_H$, $N_L C_H D_L M_L$
$N_H C_H D_L M_H$, $N_H C_L D_H M_H$, $N_L C_L D_H M_L$, $N_L C_H D_H M_L$

Where: N_L = Nature of polymer (*Entandophragma angolense*)

N_H = Nature of polymer (Hydroxypropylcellulose)

C_L = Concentration of polymer (2.5% w/w)

C_H = Concentration of polymer (10.0% w/w)

D_L = Relative density of tablet at 0.85

D_H = Relative density of tablet at 0.90

M_L = Direct compression technique

M_H = Wet granulation technique

By grouping the results into a number of sets, it was possible to assess the effect that each of the four variables had separately on the tensile strength and mucoadhesion time of the tablets. The effect of increasing the excipient N, from its 'low' level to its 'high' level on the disintegration time, tensile strength, brittle fracture index or mucoadhesion time can be determined by summing up all the values of tensile strength or mucoadhesion time of samples containing 'high' level of N and subtracting the sum of the values containing 'low' levels of N (11, 12).

Similarly, the effect of increasing the concentration of polymer (C), changing the relative density (D) or the compression technique (M) from 'low' to 'high' levels can also be determined using the adaptation of the method proposed by Woolfall (11).

To determine whether there was any interaction between two variables, the results of the combination in which they appear together at either high or low levels were summed and the sum of the other combinations were subtracted from this to obtain the interaction effects.

Montgomery (12) applied computer-based software to determine the various effects of these variables. The software (Minitab© 16), though based on the principles of Woolfall's work on product formulation (11), has been able to optimize performance in experimental processes and thus, reduced the manual calculation associated with previous processes.

Factorial experimental design allows estimation and testing of the statistical significance of the main effects and the interactions between factors. If two factors interact, then it implies that the effects of

Table 2. Values of disintegration time (DT), tensile strength (TS), brittle fracture index (BFI) and mucoadhesion time (MT) for the factorial experimental design obtained from the process parameters at low (L) and high (H) levels.

Combination codes				DT	TS	BFI	MT
N	C	D	M	(min)	(MNm^{-2})		(min)
L	H	H	H	7.71	1.291	0.277	205
H	H	L	L	7.42	0.992	0.223	308
L	H	H	L	7.39	1.799	0.268	241
L	H	L	H	6.22	1.271	0.219	209
L	L	H	L	2.09	1.779	0.158	176
H	L	H	H	2.47	1.812	0.182	207
H	H	H	H	8.37	1.331	0.290	322
H	L	H	L	2.76	2.113	0.173	200
H	H	H	L	9.71	1.798	0.281	313
L	L	H	H	2.92	2.156	0.169	214
L	H	L	L	5.96	1.123	0.217	233
H	H	L	H	6.83	1.198	0.232	321
H	L	L	L	1.94	0.817	0.122	181
L	L	L	H	1.63	1.173	0.118	203
H	L	L	H	2.10	0.982	0.131	204
L	L	L	L	1.45	1.017	0.109	184

N = nature of binder, C = concentration of binder, D = relative density of tablet, M = tabletting technique.

one factor depend on the setting of the other. Factor settings are very important in the presence of interactions since effects will not be additive in nature (12, 19, 20).

RESULTS

The results of determination of tensile strength, brittle fracture index, disintegration time and mucoadhesion time are given in Table 2.

Plots of formulation techniques and different concentrations of *Entandophragma angolense* gum on time of detachment of ibuprofen tablets are given in Figure 2. Formulations by wet compression generally show longer adhesion time than those by direct compression.

Plot of disintegration time for ibuprofen tablets (relative density of 0.9) containing different polymer concentrations and formulated using wet granulation (WG) and direct compression (DC) techniques are given in Figure 3.

The results of the factorial experimental design are given in Tables 3 and 4. A contour plot of tensile strength *versus* concentration of binder and nature of binder for tablets at a relative density of 0.90 formulated by direct compression is given in Figure 4.

DISCUSSION

The FTIR analysis showed the functional group region (4000 to 1300 cm^{-1}) having sharp peaks at 2926.85 cm^{-1} and 2853.19 cm^{-1}. These sharp peaks are characteristic of methyl C-H stretching associated with aromatic rings and carboxylic acids. The sharp peaks at 2359.93 and 2341.37 cm^{-1} are indications of asymmetric C-O stretch. The peaks obtained at 1573.69 and 1558.36 showed similar functional groups consisting of strong N=O nitroso and weak C-O stretch.

The fingerprint region consists of a characteristic peak at 1070.72 cm^{-1}. This peak confirms the presence of strong aromatic characters consisting of

Table 3. Summary of the individual coefficients of the variables on disintegration time (DT), tensile strength (TS), brittle fracture index (BFI) and mucoadhesion time (MT).

Variable factor	Coefficient	DT (min)	TS (MNm^{-2})	BFI	MT (min)
Nature of binder (X_1)	Effect p-value	0.389 0.018	-0.035 0.599	0.006 0.000	24.437 0.009
Concentration of binder (X_2)	Effect p-value	2.641 0.000	-0.065 0.338	-0.053 0.000	36.437 0.001
Relative density (X_3)	Effect p-value	0.617 0.001	0.344 0.000	0.027 0.000	2.188 0.780
Tabletting technique (X_4)	Effect p-value	-0.029 0.839	-0.014 0.834	0.004 0.000	3.063 0.697

Table 4. Summary of the interaction coefficients of the variables on disintegration time (DT), tensile strength (TS), brittle fracture index (BFI) and mucoadhesion time (MT).

Variable factor	Coefficient	DT (min)	TS (MNm^{-2})	BFI	MT (min)
X_1X_2	Effect p-value	0.242 0.035	0.015 0.762	22.563 0.001	43.13 0.001
X_1X_3	Effect p-value	0.011 0.905	0.040 0.437	1.312 0.718	0.15 0.718
X_1X_4	Effect p-value	-0.229 0.043	-0.036 0.475	3.437 0.363	1.00 0.363
X_2X_3	Effect p-value	0.227 0.043	-0.140 0.029	-0.938 0.796	0.07 0.796
X_2X_4	Effect p-value	-0.139 0.160	-0.064 0.227	-7.813 0.072	5.17 0.072
X_3X_4	Effect p-value	-0.306 0.732	-0.0984 0.086	-0.812 0.822	0.06 0.822

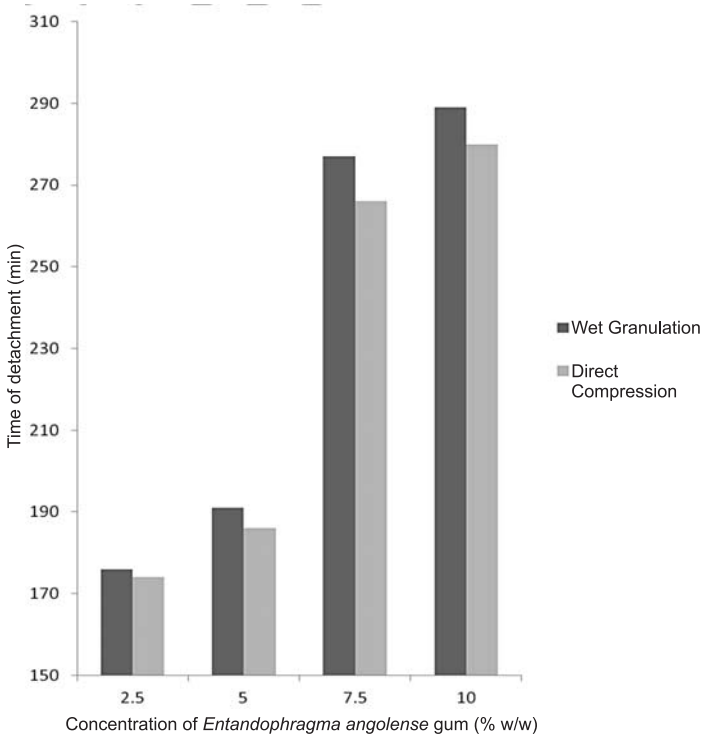

Figure 2. Plots of time of detachment (min) of ibuprofen tablets containing different concentrations of *Entandophragma angolense* gum formulated by wet granulation and direct compression techniques

C-O, C=O, C-N and C-F stretches, and weak P-H bending groups, which are present in materials like carbohydrates, starch, and natural polymers (21). The results revealed the presence of methyl, amine, phosphine and hydroxyl groups, in *Entandophragma angolense* gum. The presence of the characteristic peaks for the drug and polymers after mixing suggests the absence of a chemical reaction between *Entandophragma angolense* gum and ibuprofen.

The UV analysis of the various mixtures of *Entandophragma angolense* gum or hydroxypropylcellulose and/or ibuprofen showed no significant shift in wavelength of maximum absorption due to interaction between the polymers and the drug. The results of the peaks at wavelength range 190-300 nm for *Entandophragma angolense* gum powder in combination with ibuprofen powder at 221 nm suggest the absence of any reaction between *Entandophragma angolense* gum powder and ibuprofen.

The results of the factorial experimental design (Tables 3 and 4) provide a clear indication of the effects of the four independent process parameters: nature of binder (X_1), concentration of binder (X_2), relative density of tablet (X_3), and tabletting technique (X_4), on the four responses studied. The ranking of the individual effects on disintegration time was $X_2 > X_3 > X_1 > X_4$, on tensile strength, was $X_3 > X_2 > X_1 > X_4$ on BFI, $X_2 > X_3 > X_1 > X_4$ and on mucoadhesion time, $X_2 > X_1 > X_4 > X_3$. The rankings show the relative magnitudes of the effects of the factors on these variables. A positive effect signifies that the response variable has increased in value or magnitude, while a negative effect shows a decrease. Concentration of binder (X_2) had the largest positive effect on disintegration time of the tablets. This effect shows that changing the concentration from lower (2.5% w/w) to higher value (10% w/w) caused an increase in the disintegration time of the tablet formulations. This effect was significant ($p < 0.05$) and show that more compact tablets were formed as the binder concentration was increased, thus causing a reduction in the rate of disintegration. Two other factors (relative density of tablet, X_3 and nature of binder, X_1) also had positive effects on disintegration time. However, changing the binder from *Entandophragma angolense* gum to hydroxypropylcellulose caused an insignificant increase in both tensile strength and mucoadhesion time. Relative densi-

ty (X_3) had the largest positive effect on tensile strength of the tablets and the least effect on mucoadhesion time. This effect shows that changing the relative density from lower (0.85) to higher value (0.9) caused an increase in the tensile strength of the tablet formulations. This effect was significant ($p < 0.05$) and shows that more compact tablets were formed as the relative density was increased.

Brittle fracture index (BFI) is a measure of the tendency of a tablet to cap or laminate during decompression. It is measured by comparing the tensile strength (T_o) of a tablet with a central hole with the tensile strength (T) of a normal tablet. The hole is a built-in model defect that simulates the actual voids formed in the tablets (due to air entrapment or packing irregularities) during manufacturing (5). The voids or low density regions in a tablet are usually the weak points from which cracks emanate when stress (at the die wall) is applied to the tablet. The influence of X_2 (concentration of binder) on BFI was negative and the strongest. Hence, changing the concentration of the gum from lower (2.5% w/w) to higher value (10% w/w) causes a reduction in the BFI. This result shows that under the compressive forces employed in compaction, more of the polymer will facilitate more plastic deformation, to give tablets with reduced capping or lamination tendency.

Concentration of binder (X_2) had the highest positive effect on mucoadhesion. Mucoadhesion is a complex phenomenon which involves wetting, adsorption and interpenetration of polymer chains (22). The most critical stage in mucoadhesion is the development of strong adhesive bonds, which readily occurs as more binding sites are made available for attachment to the mucosa to occur due to increased polymer concentration (10). The implication of this is that increasing the concentration of the polymers had a direct relationship with the mucoadhesion of the tablets (Fig. 2). The polymers function as both binder and mucoadhesive, thus it is important to choose the optimum polymer concentration that will release the drug from the tablet matrix during adhesion.

Tensile strength was mostly affected by relative density of formulation (X_3) and the coefficient was positive, thus indicating that increasing the relative density led to an increase in the tensile strength of the formulations. This can be attributed to the fact that as the relative density of the tablet increases, more solid bonds are formed between the particles. This leads to increase in bond strength and hence, a subsequent

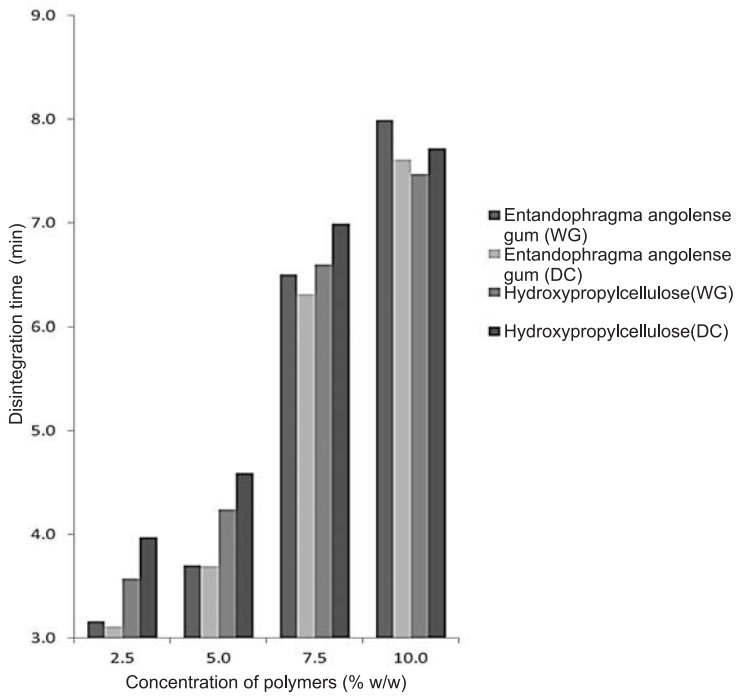

Figure 3. Plot of disintegration time for ibuprofen tablets (relative density of 0.9) containing different polymer concentrations and formulated using wet granulation (WG) and direct compression (DC) techniques

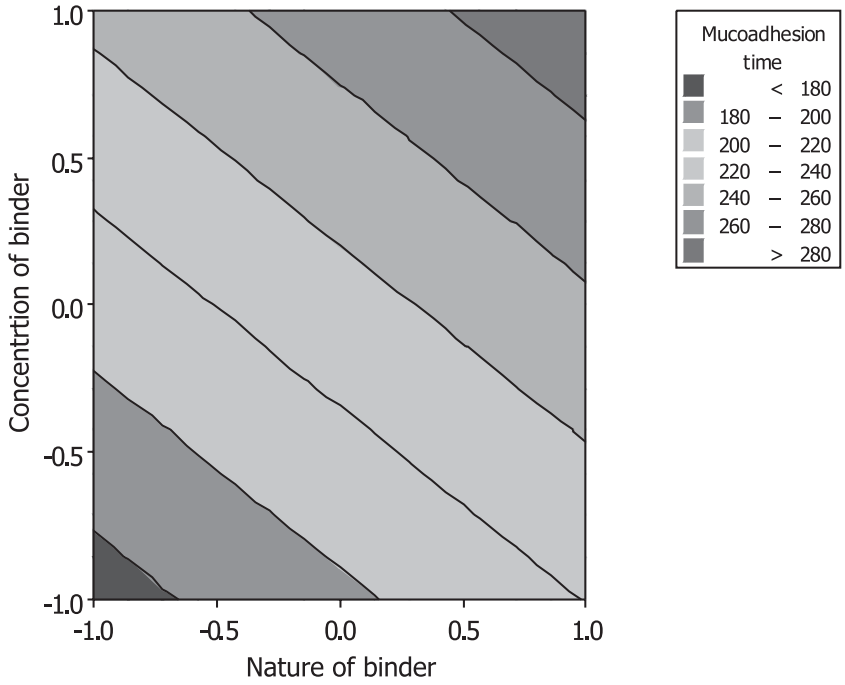

Figure 4. Contour plot of effect of interaction of concentration of binder and nature of binder on mucoadhesion time for tablets formulated by direct compression at a relative density of 0.90

increase in the tensile strength of the tablets (24). Tableting technique had a positive effect on mucoadhesion. The ability of polymers to swell in the presence of water could be responsible for the difference in the mucoadhesion time as a result of the different tableting techniques applied during the study. Thus, tablets formulated by wet granulation would adhere longer to the mucosa surface than those formulated by direct compression. This is as a result of the increased ionic strength of tablets formulated by wet granulation due to the presence of water, which will consequently enhance mucoadhesion (25).

The interaction coefficient values shown in Table 4 indicate the effects of the variable factors in combination. The ranking for the interaction effects on disintegration time was $X_3X_4 > X_1X_2 > X_1X_4 > X_2X_3 > X_2X_4 > X_1X_3$, on tensile strength, $X_2X_3 > X_3X_4 > X_2X_4 > X_1X_3 > X_1X_4 > X_1X_2$, on BFI, $X_1X_2 > X_2X_4 > X_1X_4 > X_1X_3 > X_2X_3 > X_3X_4$ and on mucoadhesion, $X_1X_2 > X_2X_4 > X_1X_4 > X_1X_3 > X_2X_3 > X_3X_4$. The results show that the interaction between the nature and concentration of the binder had the highest influence on mucoadhesion and BFI (Fig. 4), while the interaction between relative density and tabletting technique and between concentration of binder and relative density had the highest influence on disintegration time and tensile strength, respectively. Disintegration of tablets determines, to a large extent, the area of contact between the solid and liquid in the dissolution process. Many correlations have been made between disintegration time and parameters such as water penetration rate (26) and dissolution rate of tablets (27, 28). The disintegration time was mostly influenced by the interaction between tabletting technique and relative density of tablets. It was observed from the study that tablets formulated by the wet granulation technique had higher relative density and disintegration time values when compared with tablets formulated by direct compression (Fig. 3). The ability of polymers to swell in the presence of water could be responsible for the difference in the disintegration time as a result of the different tableting techniques applied during the study. The increased concentration of polymer binder which had the highest influence, in combination with relative density, on tensile strength can be attributed to the presence of more polymer particles available for bond formation and subsequently enhanced mechanical strength as characterized by the tensile strength values.

CONCLUSION

The FTIR and UV analyses suggest the absence of any interaction between *Entando-*

phragma angolense gum and ibuprofen. The variables employed in the formulations significantly affect the mechanical and mucoadhesive properties of the tablets formed. The rankings show that the greatest factor-factor interactions generally occurred between nature and concentration of the binder. This is probably due to the fact that the nature of the binder determines its plastoelastic properties and the degree of plastic deformation will undergo under compression forces. Ibuprofen tablets prepared by wet granulation method and incorporating *Entandophragma angolense* gum as binder showed lower capping/lamination tendencies and better mucoadhesive drug release profiles.

Acknowledgments

The authors are grateful to the Academic Staff Union of Nigeria Universities for the Research Grant awarded to O.A. Adetunji.

REFERENCES

1. Sinko P.J.: Dispersed systems, in Martin's Physical Pharmacy and Pharmaceutical Sciences, Sinko P.J. and Singh Y. Eds., pp. 238-242, Lippincottn Williams and Wilkins, Baltimore 2011.
2. Hillery A.M.: Advanced drug delivery and targeting: An introduction, in: Drug Delivery and Targeting: For Pharmacists and Pharmaceutical Scientists, Hillery A.M., Lloyd A.W., Swarbrick J., Eds., pp. 63-82, Taylor & Francis, New York 2001.
3. Kalu V.D., Odeniyi M.A., Jaiyeoba K.T.: Arch. Pharm. Res. 30, 884 (2007).
4. Odeniyi M.A., Jaiyeoba K.T.: Farmacia 57, 157 (2009).
5. Adeleye A.O., Odeniyi M.A., Jaiyeoba K.T.: J. Basic Applied Pharm. Sci. 31, 131 (2010).
6. Pranshu T., Satheesh-Madhav N.V.: Int. J. Biol. 21, 36 (2011).
7. Itiola O.A., Pilpel N.: J. Pharm. Pharmacol. 43, 145 (1991).
8. Adetunji O.A., Odeniyi M.A., Itiola O.A.: J. Pharm. Res.: 6, 54 (2007).
9. Adetunji O.A., Odeniyi M.A., Oridupa O.O., Itiola O.A.: Proceedings of the Pan-African Summer School on Nanomedicine. 4th - 10th November, 2012. Swai, H. and Nyamboli, B. Eds., p. 51, Pretoria 2012.
10. Odeniyi M.A., Babalola A., Ayorinde J.O.: Braz. J. Pharm. Sci. 49, 95 (2013).
11. Woolfall R.C.: Soap Perfume. Cosmet. 37, 565 (1964).
12. Montgomery D.E.: The Design and Analysis of Experiments. pp. 19-41, John Wiley and Sons, New York 1991.
13. Uzeala J.: Classification and uses of natural gums, in The Useful Plants of West Africa;. Burkhill, H.M. Ed. 2nd edn., pp. 173-185, Royal Botanical Gardens, Kew, UK 1988.
14. *Entandophragma* Family in: The Useful Plants of West Africa. Burkhill H.M. Ed., 6th edn. pp. 661-662, Royal Botanical Gardens, Kew, UK 1997.
15. Adetunji O.A., Odole M.O., Itiola O.A.: Proceedings of the Humboldt International Conference (Alexander Von Humboldt Foundation) on Climate Change and Sustainable Development: Cultural and Techno-environmental Responses in West Africa, 11th – 15th October, 2011. Adebowale, K.O. et al. Eds., pp. 17-18. University of Ibadan, Ibadan, Nigeria.
16. Alur H.H., Pather S.I., Mitra A.K., Johnston T.P.: Pharm. Dev. Tech. 4, 347 (1999).
17. Sofowora A.: Medicinal Plants and Traditional Medicine in Africa. pp. 134-156. Spectrum Books Ltd., Ibadan 1993.
18. Uhumwangho M.U., Okor R.S., Eichie F.E., Abbah C.M.: Afr. J. Biotechnol. 5, 1950 (2006).
19. Myers R.H., Montgomery D.C., Anderson-Cook C.M.: Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 3rd edn. Wiley, New York 2009.
20. Ayorinde J.O., Itiola O.A., and Odeniyi M.A.: Acta Pol. Pharm. Drug Res. 70, 557 (2013).
21. Arora G., Malik K., Rana V., Singh I.: Acta Pol. Pharm. Drug Res. 69, 725 (2012).
22. Khutoryanskiy V.V.: Macromol. Biosci. 11, 748 (2011).
23. Shah K.U., Rocca J.G.: Drug Deliv. Technol. 4 (5), 1 (2004).
24. Alebiowu G., Itiola O.A.: Drug Dev. Ind. Pharm. 28, 663 (2002).
25. Rahamatullah S., Thakur R.R.S., Martin J.G., Woolfson A.D., Donnelly R.A.: J. Pharm. Biol. Sci. 31, 89 (2011).
26. Shangraw R.F., Mitrevej A., Shah M.: Pharm. Technol. 4, 49 (1980).
27. Najib N., Jalal I.: Int. J. Pharm. 44, 43 (1988).
28. Singh J., Kaur L., McCarthy O.J.: Food Hydrocoll. 21, 1 (2007).

Received: 11. 04. 2014